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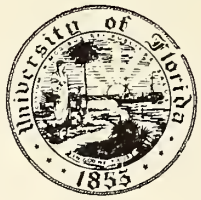

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MEASUREMENTS

EQUIPMENT and TECHNIQUE

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HEADQUARTERS FOR ELECTRICAL MEASUREMENT

GENERAL ELECTRIC

SCHENECTADY, N. Y.

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MEASUREMENTS For VICTORY

By I. F. KINNARD
Executive Engineer, Meter and Instrument Engineering Departments
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A MEASUREMENT of some quantity or condition is a factor vital to the success of almost any operation or undertaking. This measurement may be mechanical or electrical in nature, or it may be related to other branches of physical science, but wherever exact information is required to give knowledge of conditions or for control purposes, some measuring instrument or meter must be utilized.

This fact was never more apparent than in modern warfare, where victory depends on the skillful manipulation and co-ordinated functioning of large quantities of mechanized equipment. For the successful operation of any ship, plane, tank, army, factory, or almost any other war activity, measuring instruments are necessary as a medium by which the existing conditions are indicated or recorded to provide information for human or automatic control. As such, instruments are the sentries, the secret service, and the signal corps for all sorts of mechanisms and equipment, by which those responsible are informed of changing situations so that they can take the steps required for successful operation. In certain cases, such as the automatic pilot and controls for aircraft, the hand of man is entirely eliminated and instruments not only discern the conditions but also take the proper corrective action whenever necessary. Instruments now take their place alongside shells, bombs, machine guns and artillery as essential equipment for the fighting forces.

The instrument industry has therefore been assigned a war objective which calls for at least as much ability and perseverance as that needed by any other industrial group engaged in the war effort. Demands for measuring devices are constantly increasing. Many of these are, of course, for existing types of instruments, or for those having minor modifications. Equally urgent, however, has been the demand for instruments to perform new types of measurements to which existing devices cannot be applied. The accomplishing of this part of the task has required inventive ability and design skill of a very high order.

Providing War Instruments

It was fortunate and particularly helpful in the present emergency to have available a trained and seasoned corps of measurement engineers. The long background of instrument craftsmanship in the factory personnel was also at hand to serve as a nucleus for training thousands of new employees required to handle a tremendous production of measuring devices. This trained personnel and background of instrument skill have combined to make outstanding contributions to the war effort.

Their contributions may be conveniently classified and discussed under inventions, designs, materials, and improved methods and processes. In this short article, it is possible to mention only a few of the

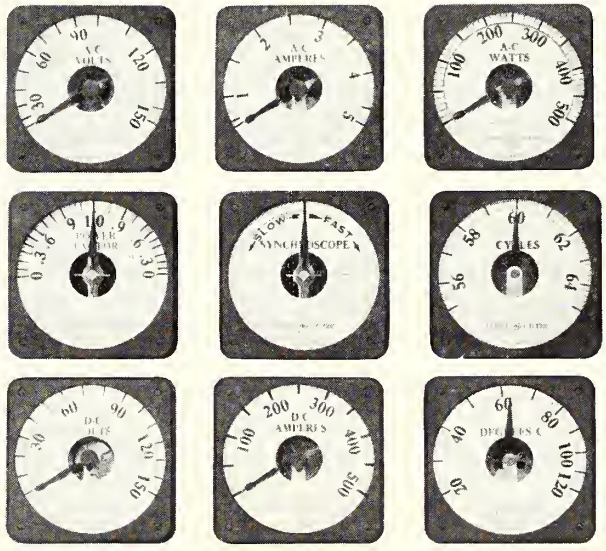

Fig. 1. Concentric-scale switchboard instruments. These units provide a 6.80-in. scale in a 4.25-in. case

major accomplishments under these various headings. The ability to do an outstanding job in each of these different phases of the work is essential to quick action in attaining the wartime objectives.

New Inventions and Designs

As a rule, inventive genius goes hand in hand with design, which is the medium for materializing the invention. Contributions may be in the form of a fundamental idea for a new or improved way to accomplish the desired results. On the other hand, the new design of an instrument may employ well-known principles, but nevertheless be a real contribution because of its technical excellence, nicety of mechanical

design, or other desirable features, such as small size, light weight, and freedom from operational difficulties.

For example, the concentric-scale switchboard instruments, with the unique feature of 6.80-in. scales in 4.25-in. cases, shown in **Fig. 1**, were developed just prior to the present emergency by utilizing fundamentally new ideas. The easy readability and compactness of these instruments make them highly desirable for shipboard installations where space is at a premium. To meet the requirements of modern fighting vessels, however, it was necessary to adapt these instruments to withstand the extremely high shocks caused by gunfire, bombs, etc.

Compactness and sturdiness are also essential for the miniature instruments used in fighting planes, tanks, and field communication equipment. By using the concentric-magnet design, portable instruments are similarly well suited to the job of testing electrical war equipment in order to maintain it in first-class shape. The inkless recorder design completes the group of instruments required for the measurement of strictly electrical quantities in connection with war equipment.

For fighting planes another group of electrical instruments has been developed to measure such nonelectrical quantities as the angular position of flaps and wheels, the liquid level in gas tanks and the speed of the engines. In many of these designs, the operation of the instrument depends on a fundamental invention, the d-c Selsyn; in others, well-known principles have been adapted to meet the exacting requirements of modern aerial warfare. A display of these aircraft instruments is shown in **Fig. 2**. Under development at the present time are other aircraft instruments of such secret nature that they cannot be publicly mentioned.

In addition to these devices strictly classified as instruments, such related equipment as instrument transformers and time switches have been adapted to combat applications. These, together with instruments, watthour meters, and demand meters, are also serving in the present emergency by doing their part to improve efficiency, to maintain operations, to conserve electricity, and to accomplish the many other measurement jobs required by wartime industry.

Fig. 2. Various aircraft instruments including working model of position indicator and gasoline indicator

Materials

Many of the designs of war instruments which fill unusual measurement requirements depend on contributions made in the form of new material having just the right physical characteristics to meet specific needs. Such contributions usually involve meticulous, painstaking laboratory work to discover how the required characteristics can be obtained, and to ascertain other necessary facts in connection with the suitability and useful life of the material. The selection of materials is one of the most difficult and important tasks of the measurements engineer, who is concerned particularly with the permanence of physical, magnetic, and electrical characteristics, knowing that any changes may entirely destroy the precise measurement that he is endeavoring to accomplish.

The recent rapid development of new permanent magnets used in electrical instruments for many different purposes is an excellent example of both the many problems which are encountered and the contributions that have been made by the use of new materials. Not the least of these problems involves the stabilizing treatment which must be given to every instrument permanent magnet to assure sustained high accuracy but which differs for each type of magnet alloy. The permanent-magnet alloys, which have made possible many of the new designs, are Comol, an alloy of cobalt, molybdenum and iron; Cu-ni-fe,

an alloy of copper, nickel and iron);[2] sintered oxide;[3] a silver, manganese, aluminum alloy;[4][5] alnico II; and the newly developed "super" permanent magnet alloy, alnico V.[6]

Other alloys, whose unusual characteristics are employed in instruments to provide superior performance, include temperature-sensitive magnetic materials, such as Calmalloy,[7] first developed for compensating watthour-meter temperature errors, and various alloys of nickel and iron. The chief purpose of these materials is to assure high accuracy over wide ranges of ambient temperature. Also developed for this same purpose but applied in a different fashion are an aluminum alloy of extremely low temperature coefficient of resistance and tellurium and silver-tellurium alloys which have large negative coefficients.[8]

Nonmetallic materials, whose development and use have aided in the solution of wartime measurements problems, include special lubricants for fine bearings; crepe paper for instrument transformer insulations; and hard-glass vee jewels, a substitute for scarce sapphire jewels.[9]

The substitution for other scarce materials in such noncombatant devices as watthour meters has been accomplished without appreciably affecting the operation of these devices, and constitutes an additional contribution to the over-all war program.

Methods and Processes

Another important contribution to the successful production of instruments is the development and selection of proper methods or processes for the fabrication of parts or for finishing and assembling the unit. The methods used in manufacture can mean the success or failure of the device in service.

Trained personnel that specializes in this difficult and important field has been built up over the years. Many of the processes that are in use today have made possible superior performing instruments and efficient manufacture. Examples of these processes are the casting of alnico magnets, in which use is made of scrap and unrefined ores as sources of scarce materials; the photographic process for making instrument scales; the precise winding and assembly of small instrument armatures; and the welding of tiny instrument parts, such as thermocouple wires for radio-frequency instruments. Other instrument parts requiring specialized methods and techniques include pivots, control springs, coils, and hard-glass vee jewels. The testing equipment built for many new war instruments has required technical ability and ingenuity of as high an order as that needed to design the instruments themselves.

The Record to Date

The time factor is really the most important one of all in this stupendous war effort in which we are all engaged. It would avail little to develop and produce the most accurate and reliable instruments ever conceived, if they were not ready at the proper time to be co-ordinated with the over-all program of our armed forces and industrial war effort. This obligation has been recognized and almost everything has been subordinated to the one idea "of getting the job completed in the shortest possible time."

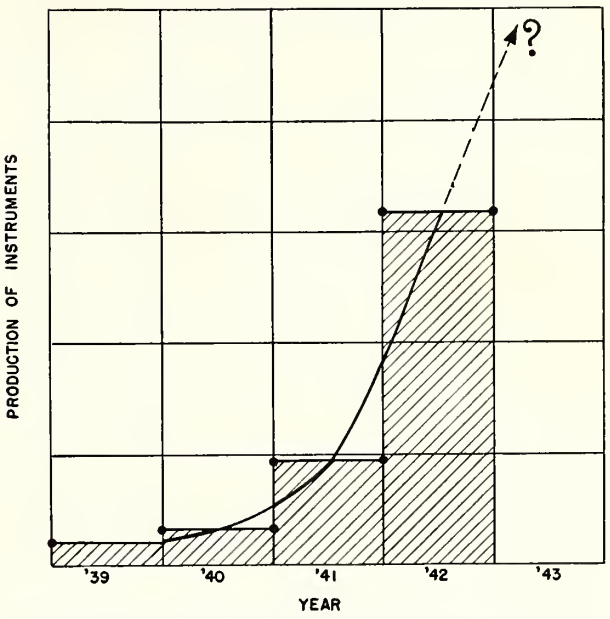

Fig. 3. Relative output of all types of instruments for the years 1939 to 1942 inclusive

It is not permissible to give actual production figures, but in **Fig. 3** is shown the relative increase in output of instruments of all types from 1939 to 1942 inclusive. Some of these devices are standard types, but the largest part consists of new designs and modified designs to meet the requirements of the Army, Navy and industry engaged in vital war work. The output will undoubtedly continue to grow in 1943, and will remain at a very high level as long as the emergency continues. This tremendous increase has been obtained partly by converting personnel and facilities from other work not considered so essential, and partly from expanding facilities. This record speaks for itself and indicates a loyal, capable, trained, and well co-ordinated personnel, who are giving everything they have in designing, developing, and building the devices needed to attain our objective of providing measurements for victory.

(2) U. S. Patent, 2,196,824, Dahl, et al.
(3) U. S. Patent, 2,102,409, H. T. Faus.
(4) "Some Magnetic Alloys and Their Properties," by H. H. Potter, *Philosophical Magazine*, vol. 12, p. 255, August 1931.
(5) U. S. Patent, 2,247,804, H. T. Faus.
(6) "Progress in Engineering Knowledge During 1941," by P. L. Alger, General Electric Review, p. 88, February 1942.
"Alnico—Properties and Equipment for Magnetization and Test," by B. M. Smith, General Electric Review, vol. 45, p. 210, April 1942.
(7) "Temperature Errors in Induction Watthour Meters," by I. F. Kinnard and H. T. Faus, *Transactions AIEE*, 1925.
(8) "Resistance Characteristics of Tellurium and Silver—Tellurium Alloys," by H. T. Faus, *Transactions AIEE*, 1937.
(9) "A New Jewel for Indicating Instruments," F. K. McCune and J. H. Goss, *AIEE Technical Paper* 42–134.

AIRCRAFT INSTRUMENTS

The modern airplane is a very intricate mechanism, and its electrical instrument systems are the "nerves" that transmit to the crew indications of the condition and operation of the components upon which performance and safety depend

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Charles F. Savage.

THE large number of indications which must be transmitted accurately to the instrument board of a modern airplane has created a demand for instruments of small size, high accuracy, and light weight. Electric instruments are particularly adapted to meet this demand.

General Electric aircraft instruments utilize two principles of operation. The first is the d-c Selsyn telemetering system used in a variety of instruments for transmitting to the instrument board such indications as pressure, temperature, liquid level, and the

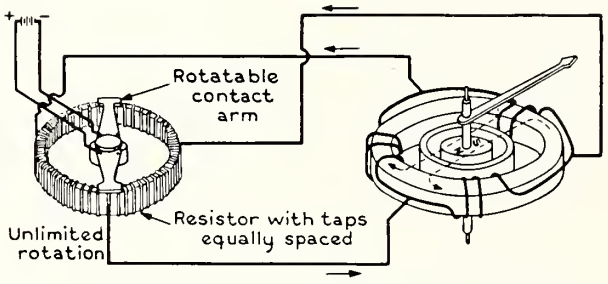


Fig. 1. Diagram of the circular rheostat transmitter and the indicating elements

position of the various controlling members of the airplane. The second principle used is a three-phase synchronous system which has certain advantages when used for indicating engine speed and particularly so when used to indicate synchronism of more than one engine on multi-motored planes.

D-c Selsyn Devices

The principle of operation of the d-c Selsyn instruments may be obtained by referring to **Fig. 1**. The circular rheostat transmitter is a continuous single-layer winding with two brushes supplying d-c at diametrically opposite points. The indicator consists of ferromagnetic laminations around which are wound three coils, a polarized permanent-magnet rotor to which is attached the pointer, and a copper damping cylinder. The distribution of voltage around the transmitter resistor sets up a magnetic flux diametrically across the indicator ring. The polarized permanent-magnet rotor on the indicator shaft aligns itself with this flux and, since the field will follow the brushes as they are rotated, a definite and accurate indication of transmitter arm position is obtained. The windings shown are similar to delta-connected three-phase windings. Connections similar to other polyphase windings may also be used, and the windings may be concentrated in coils rather than being uniformly distributed on the core.

The use of a permanent magnet of high coercive force, in combination with a copper damping shell fixed in the air gap between the rotor and the stator, gives effective damping combined with high torque. Damping by a permanent magnet used in this manner involves no power loss as would be the case if an alternating field were used. The torque is a function of the product of the rotor and stator fluxes. Since the rotor field is of much higher magnetomotive force than the stator field, and since its excitation involves no electrical losses, it is evident that the inherent torque-producing effectiveness is high. The high torque-to-weight ratio obtainable with this system is one of its outstanding advantages. This makes it possible to use a comparatively light moving element which requires neither ball nor jewel bearings since the frictional errors are not appreciable with steel and bronze bearings. As these bearings are lightly loaded they withstand severe vibration very well.

By using brushes of precious-metal alloys, operating at carefully determined pressures, a reliable contact is obtained with very little friction.

Variations

In the transmitter shown in **Fig. 1**, the output voltage passes through 360 electrical degrees for each revolution, so that the ratio of angular motions of the transmitter indicator is unity. By making the number of evenly spaced taps equal to $3n$, where n is the number of indicator revolutions per transmitter revolution, it is possible to obtain a ratio equal to any whole number. Brushes of opposite polarity must be 180 electrical degrees ($360/(2n)$ angular degrees) apart. In order to utilize the full capacity of the winding, $2n$ brushes must be used, but the transmitter is operable with only two brushes.

Two or more indicators may be operated in parallel in connection with any of these transmitters. The only effect on their operation is to lower the torque in proportion to the reduction in current through each indicator.

Since there is no torque acting on the indicator when the power is disconnected, the pointer will remain unchanged in position. For applications where an indication of power failure is desired, the indicator is provided with a small fixed permanent magnet which attracts the rotor magnet to a position at which the pointer is off the calibrated part of the scale. Due to the high torque of the instrument, it is possible to use a fixed magnet strong enough to provide a reliable indication of power failure without having any significant effect on the accuracy.

Characteristics

The characteristics of this instrument are as follows:

(1). Each indicator element weighs 25 grams. It requires a 1¼ in. diameter hole for panel mounting.

(2). The power required by the transmitter and indicator combination is 2.0 watts. With two indicators connected to one transmitter, the power required is 2.4 watts.

(3). Varying the voltage of the supply does not affect the indication provided no power-failure indicator is used. With the power-failure indicator a variation of 10 per cent in the voltage will cause a maximum error of one degree.

(4). The average torque for 60-degree indicator deflection is two millimeter-grams.

(5). Temperature effect on indications is negligible because of the symmetry of the circuit.

(6). The waveform of the voltage between taps in the transmitter is interesting. At no load the waveform is triangular with the tops cut off flat. With load, the sides and tops of the wave bend inward. The change is of such nature that at any given point the ratio of voltage between one pair of taps to that between another pair of taps does not change with load; hence an indicator connected to the transmitter will not change its calibration when another indicator is placed in parallel with it. The peculiar shape of the voltage wave does prevent the indicator from following the transmitter linearly. This inherent deviation has been determined to have a maximum peak of 1.3 degrees. The peaks occur at six points above the axis, and six points below the axis.

Applications

One of the first applications of the d-c Selsyn was for the remote indication of the positions of the landing gear and wing flaps on an airplane. For this purpose four elements were mounted in a single standard size 2¾-in. instrument case, one element being used for each of the three landing wheels and one for the flaps as shown in **Fig. 2**.

The remote indication of oil and fuel pressure is accomplished by connecting a bellows to the oil or fuel pressure line. The motion of the bellows is utilized to rotate the transmitter brushes.

The temperature transmitter has a bimetal helix which rotates the transmitter brushes as the temperature changes.

The manifold-pressure transmitter has a partially evacuated sealed bellows in a pressure-tight compartment and the manifold pressure is applied to the outside of the bellows. Motion of the bellows is transmitted mechanically through a flexible wall to the d-c Selsyn transmitter. Temperature compensation is obtained by having the right amount of gas in the sealed bellows.

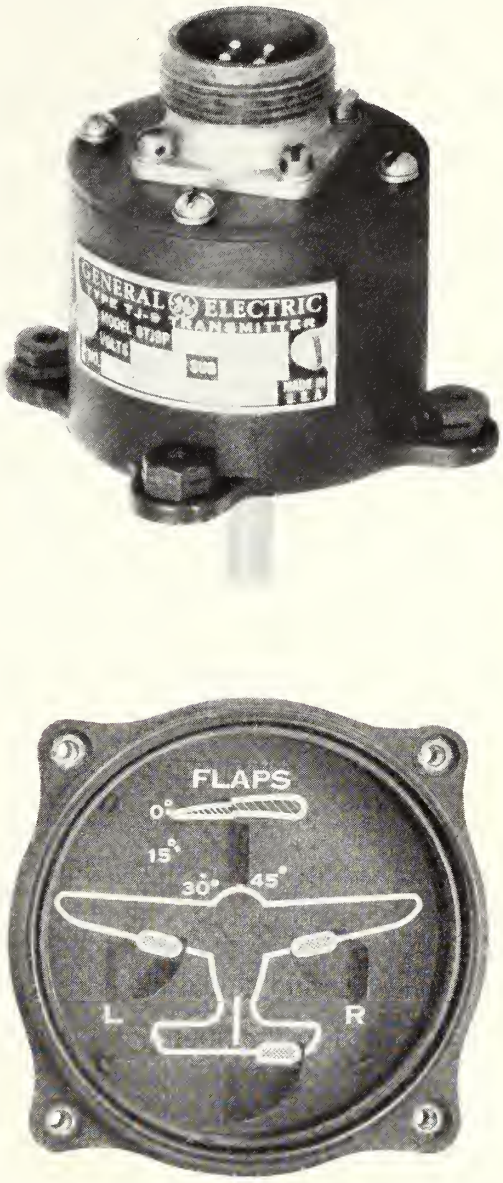


Fig 2. The position transmitter, and position indicator

The differential fuel-pressure transmitter is similar to the manifold-pressure unit except the bellows is not evacuated. The fuel pressure is connected to the inside of the bellows, while the surrounding chamber is connected to the manifold. The bellows deflection is then proportional to the differential pressure.

As shown in **Fig. 3**, the liquid-level measurement utilizes the motion of a float to actuate the transmitter brushes. Magnetic coupling is used between the

transmitter outside the tank and the float mechanism inside the tank so as to provide a positive gasoline seal.

Tachometer Equipment

As the size and speed of aircraft increased, due to the availability of more powerful engines, it became necessary to control the engine speed more accurately in order to obtain the most economical engine operation. High-altitude operation presented the problem of increased accuracy of engine-speed indication throughout the temperature range from approximately −50 C to +50 C, requiring marked improvement in temperature compensation. Due to the more accurate indication required, it became necessary to obtain tachometer equipment with a long scale length to provide more accurate readability.

The problems outlined in the preceding paragraph were solved by the development of a tachometer operating on the magnetic-drag principle consisting essentially of a three-phase a-c generator mounted on the aircraft engine and an indicator consisting of a synchronous motor operating a magnetic-drag assembly.

The problem of changes in the generator output voltage was eliminated by the adoption of the generator and synchronous-motor combination. This constituted a frequency-sensitive system for transmitting an indication of engine speed to the indicator with absolute accuracy.

For many installations it is desirable to obtain engine-speed indication at two different stations in the aircraft. This system is ideal for this application, since there is no change in indication due to the addition of a second indicator in parallel with the first; synchronous-motor operation in each indicator is only dependent upon the availability of sufficient power to operate both motors.

Primary factors of light weight and small size, plus reliable operation, were problems which were

Fig. 3. The liquid-level transmitter

met in the design of the generator shown in Fig. 4. Light weight and small size were obtained by making use of a permanent-magnet rotor with high magnetic-energy content. The physical dimensions of the rotor required a magnetic material having high coercive force, due to the short magnet length and to prevent demagnetization. Due to the extreme vibration

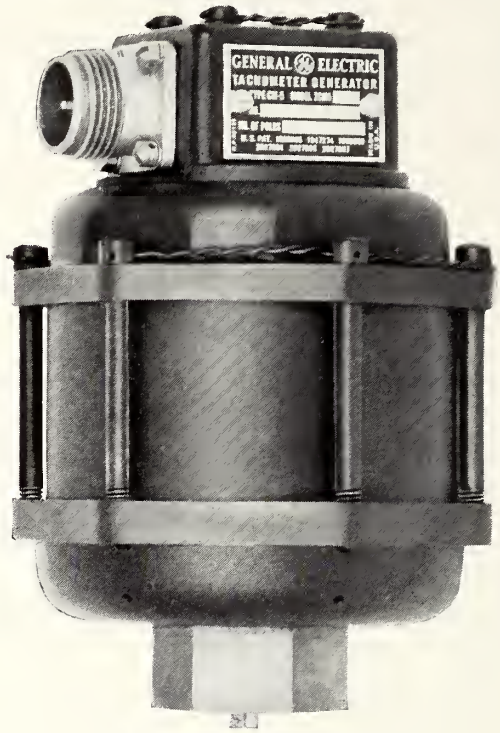


Fig. 4. The tachometer generator

encountered it is necessary to have a material which is not readily affected by vibration. Alnico offered the answer to those requirements and is cast directly on the rotor shaft.

As the aircraft-engine accessory drives often transmit, to a considerable extent, torsional oscillations originating at the crankshaft, the tachometer generator includes a long, slender drive shaft, carried within the hollow rotor shaft, having sufficient flexibility to prevent failure of the drive key as well as to accommodate small misalignments between generator and engine pad.

Two limiting conditions are necessary with regard to output of the generator; first, with a single indicator connected to the generator, the voltage output at normal cruising speed must not exceed a certain limit in order to prevent excessive temperature rise in the indicator; and second, at the lowest operating speed, with two indicators connected to a single generator, the output voltage must exceed a certain minimum value so that there will be sufficient power output available to start and operate the indicators at any temperature. These requirements were met by taking advantage of the properties of the alnico rotor which permitted shorter, hence lower resistance, turns, resulting in improved voltage regulation.

Indicator

The indicator is shown in **Fig. 5**. As briefly described in a previous paragraph, it includes a synchronous motor and a magnetic-drag assembly.

The requirements for a satisfactory motor include the ability to start and to run synchronously at any speed throughout the operating range when two indicators are connected to a single generator, and yet not overheat when connected singly to a generator. Since the generator output decreases with a decrease in engine speed, it is necessary that the indicator start with very low input at the lowest speeds. It is essential that the motor should meet these requirements with minimum weight and size, and yet be simple and rugged for long life and ease of maintenance.

A unique motor assembly in conjunction with a conventional three-phase wound stator offered a solution to these requirements. The rotor assembly consists of a polarized rotor, a spring, and a hysteresis disk. The starting torque is supplied by the polarized rotor at low engine speeds, where the frequency is too low to produce appreciable torque in the hysteresis disk. As the generator frequency is increased by increasing engine speeds, a greater share of the torque is produced by the hysteresis disk and the polarized rotor assists by bringing the motor into synchronism.

In order for the polarized rotor to perform the above functions, it was necessary to design a rotor with an extremely low moment of inertia and with high magnetic strength. A sintered oxide material was used for this application.

The hysteresis disk is produced from an alloy of copper, nickel, and iron. It is heat-treated to produce the desired magnetic characteristics.

Bearings for the indicator motor presented a major problem. Since the generator output decreases as the generator speed is lowered, resulting in a very low indicator input at engine idling speeds, low friction in the bearings is required for proper starting. In addition, bearing lubricant gradually becomes more viscous as the temperature is decreased, this also resulting in increased bearing drag. High-quality ball bearings and controlled amounts of special tachometer lubricant successfully solved this problem.

The magnetic-drag assembly consists of the rotating-magnet assembly and the armature assembly. Since the rotating-magnet assembly is a part of the rotor assembly of the synchronous motor, it is necessary to obtain a magnetic assembly with as low a moment of inertia as possible. This will reduce the required torque on the magnetic-drag disk. Five pairs of alnico magnets, concentrating the flux near the outside edge of the magnetic-drag disk, accomplish this with minimum weight of magnetic material.

The spring assembly in the armature permits 3½ revolutions of the pointer. Two springs are effectively connected in series by a spring arm joining the outer turns of the two springs. The inner turn of one spring is fastened to the shaft and the inner turn of the second spring is fastened to an adjusting arm mounted on the element plate.

The magnetic-drag disk is made from a special aluminum alloy in order to obtain minimum weight with the requisite conductivity and temperature coefficient. It is essential to obtain a temperature coefficient within certain definite limits in order to obtain optimum accuracy of indication for rapidly changing temperatures. Data for several disk materials are indicated in Table I, where the advantage of the aluminum alloy is evident due to the combination of light weight and low temperature coefficient.

Fig. 5. The tachometer indicator

TABLE I

COMPARISON OF DISK MATERIALS

Material	Temperature Coefficient (% per deg C)	Conductivity	Density (gm per cc)
Aluminum	0.34	60	2.7
Copper	0.385	100	8.9
Aluminum alloy	0.040	12	2.8
Copper-manganese	0.036	15	8.8

Temperature Compensation

Temperature compensation is accomplished by the addition of temperature-sensitive magnetic shunts placed in the magnetic assembly. This material is a nickel-iron alloy. Provision is made in the indicator for accomplishing full-scale, zero and balance adjustments. Table II lists the pertinent details for a representative tachometer installation consisting of two indicators and one generator.

A synchroscope, mounted in a standard 1⅞-in. instrument case, provides a simple accurate visual means of synchronization on multi-engined installations. Output from each of two tachometer generators is used to operate this instrument.

Conclusion

From the basic design description given it is possible to make many modifications as dictated by

Table II

DATA ON REPRESENTATIVE TACHOMETER INSTALLATION (TWO INDICATORS, ONE GENERATOR)

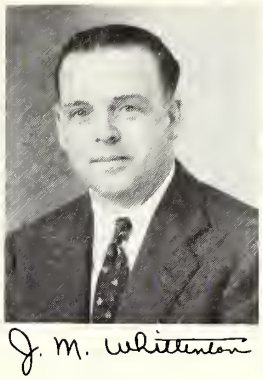
Operating Range	500-3500 rpm (250-1750 rpm generator)
Accuracy (+25 C)	±10 rpm
Generator weight	2.5 lb
Indicator weight (each)	1.0 lb
Indicator input (2400 rpm)	5 w
Position error	6 rpm
Magnetic effect (5 in. from compass needle)	0.5 deg
Indicator temperature rise (2400 rpm)	35 C
Generator temperature rise (2400 rpm)	20 C

particular applications or needs. The d-c Selsyn instruments have single, dual, triple, or quadruple elements in a single case. Application of the position-indicator instruments includes cowl flap, oil cooler, bomb door and radio-loop position indicators as well as the standard landing gear and flap indicators.

The high degree of accuracy and stability in the tachometer has caused it to be used for many applications other than for aircraft use, such as, standards in laboratories, dynamometers, and on stationary engines. The over-all acceptance of these instruments is evidenced by their widespread use on military and commercial aircraft.

MINIATURE INSTRUMENTS

Small and compact, and of light weight, these reliable indicating instruments are ideal for use in portable and semiportable equipment



By J. M. WHITTENTON
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General Electric Company

DURING recent years few factors have been of greater importance in the successful growth of industry than those involved in the exact measurement and control of physical, chemical, and electrical processes. Electrical measuring instruments have played a prominent part in many of these peacetime developments.

Knowledge, accumulated to suit civilian need, is now being applied to the war effort in ever-increasing quantity. Old applications of indicating instruments have been expanded and new applications have been born. These have played a prominent part in the development of radio communication, ordnance control, power-plant equipment both large and small, industrial equipment, and portable units, as well as numerous devices for the measurement of electrical and nonelectrical quantities.

Indicating instruments are usually classified into three groups; namely, portable, switchboard, and miniature types. Each group is designed to fulfill certain needs of measurement and therefore the instruments in a particular group have features which better adapt them to definite applications.

This article is primarily concerned with the third group; namely, miniature instruments. As the name implies, these are small panel-type or portable indicating instruments, having a scale length ranging from 1.5 to 3.5 in. and a normal accuracy within ±2 per cent of full scale. Some of the more common sizes and shapes of these instruments are shown in **Fig. 1**.

There is a great demand for small, compact, lightweight, and reliable measuring devices for use in portable and semiportable equipment. This is especially true for the radio and other electronic equipments which have become so essential in all military and naval operations on land, in the air, and on the sea. Miniature-type panel instruments offer their time-tested and performance-proven designs to meet the many requirements. A relatively short time ago, their use was restricted primarily to a small field of applications, such as battery chargers, automobile panel indicators, ammeters and voltmeters for use on portable testing equipment and a few miscellaneous testing applications. Times have changed, however, and with the increasing use of electrical equipment, more people are becoming conscious of the importance of knowing whether their equipment is operating efficiently.

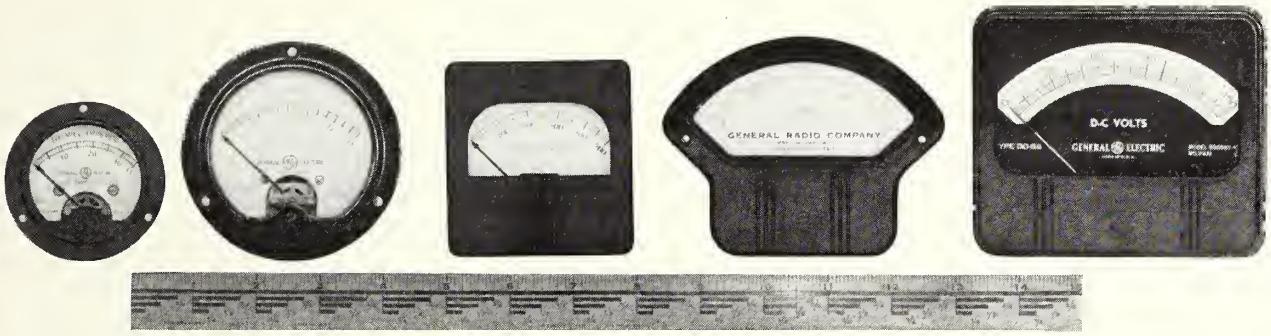

Fig. 1. An illustration of the variety of modern miniature instruments. Their small size is indicated by the 15-in. rule beneath them

The lists in Table I, which are by no means complete, will serve to show some of the widespread application for these small instruments.

During the coming year, quantities of these instruments will be required in excess of any yearly quantities heretofore manufactured . To fulfill the necessary requirements, the group of instruments of the miniature type must encompass a wide range of d-c voltage, d-c current, a-c voltage, a-c current, rectified a-c voltage and current, and radio-frequency current. Such a range of measurements can be satisfied by two basic mechanisms and two auxiliary units, as listed in Table II, for all sizes of instruments shown in **Fig. 1.**

While the fundamental design of miniature instrument mechanisms has not changed during the past few years, the range of measurements has increased due to improved materials and better ways of doing things. A brief description of the mechanisms listed in Table II and an outline of their theory will now be given.

Class I: Permanent-magnet Moving-coil Mechanism for Measuring D-c Volts and Amperes

The permanent-magnet moving-coil mechanism (**Fig. 2**) is the most commonly used type of element for the measurement of direct-current voltage and current. The theory of operation is well known and will not be repeated here. It has the highest sensitivity of the instruments of the magnetic type and is operated by the minimum of energy. The average one-milliampere unit with about 70 ohms resistance has a sensitivity of 1000 ohms per volt and requires only 0.07 milliwatts of energy. The scale distribution of this type of instrument is linear, due to constant magnetic flux across the air gap in which the moving coil turns.

Class II: Permanent-magnet Moving-coil Mechanism for Measurement of Rectified A-c Volts and Amperes

In the measurement of rectified alternating currents and voltages, a full-wave dry-type copper-oxide rectifier is used in conjunction with the permanent-magnet moving-coil mechanism described under Class I. The assembly (*a*), construction (*b*), and schematic diagram (*c*) are shown in **Fig. 3**.

This is recognized as the best available means for use in the measuring of a-c currents and a-c voltages in low-power circuits. With instruments of this type it is possible to measure, full scale, a-c voltages as low as one volt and a-c currents as low as 40 microamperes, resulting in a minimum power drain from the circuit.

The d-c moving element indicates the average value of current, while the root-mean-square value is

TABLE I

SOME APPLICATIONS OF AMMETERS AND VOLTMETERS

Measurement of Voltage and Current
Aircraft panel equipment
Arc welders
Automotive testing devices
Carrier-current devices
Electronic units
Industrial control panels
Locomotive generating equipment
Power rectifiers
Portable testing devices
Radio transmitters and receivers
Small panel-type switchboards
Searchlight control
Portable power plants
X-ray equipment and many others

Measurement of Other Quantities in Terms of Voltage and Current
Light
Temperature
Speed
Lightning
Vibration
Noise
Location detection
Moisture content
Dimensions
Volume level in broadcast and public-address equipment
Resistance
And numerous other factors incident to industrial processes

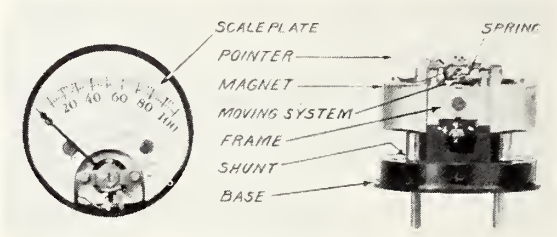

Fig. 2. Permanent-magnet moving-coil mechanism of a d-c miniature instrument

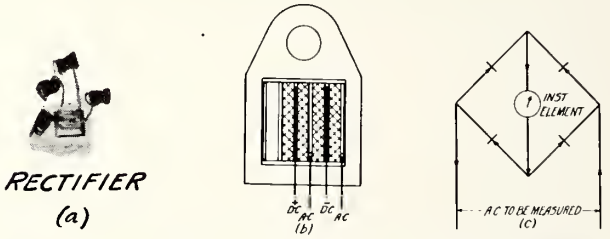

Fig. 3. Assembly, construction, and schematic diagram of full-wave copper-oxide rectifier for use in miniature instruments

TABLE II

Class	Kind of Mechanism	Quantity Measured	RANGE OF FULL-SCALE MEASUREMENTS	
			Self-contained Instrument	With External Equipment
I	Permanent magnet moving-coil (D'Arsonval type)	D-c current D-c voltage	20 microamp to 50 amp 10 millivolts to 500 volts	10 amp to limit of shunt 500 volts to limit of external resistor
II	Permanent magnet moving-coil with copper-oxide rectifier	Rectified a-c current	40 microamp to 15 milliamp	
III	Permanent magnet moving-coil with thermocouple	R-f current	2 milliamp to 20 amp	20 amp to limit of thermocouple
IV	Modified soft-iron vane principle	A-c current A-c voltage	5 milliamp to 100 amp 1 volt to 500 volts	5 amp to limit of transformer. 150 volts to limit of transformer or limit of resistor

desired. The instruments are therefore calibrated on sine wave and marked in rms values. To read d-c with this combination, an error of ±11.1 per cent will be evident when a mean of the d-c readings is taken. When the wave is distorted, and if the wave form is known, a correction factor can be applied.

The scale distributions vary from inverse logarithmic on low-rated voltmeters to uniform distribution above 15 volts at sensitivities of 1000 ohms per volt and higher. Variations in distribution are due to the rectifier resistance characteristics at low currents.

Class III: Permanent-magnet Moving-coil Mechanism for the Measurement of Radio-frequency Currents

The thermocouple is also used in conjunction with the permanent-magnet moving-coil element to measure alternating currents. The assembly (*a*) and construction and schematic diagram (*b*) are shown in **Fig. 4.**

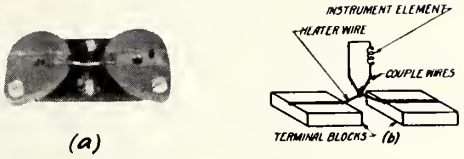

Fig. 4. Assembly, construction and schematic diagram of internal heater type thermocouple for use in miniature instruments

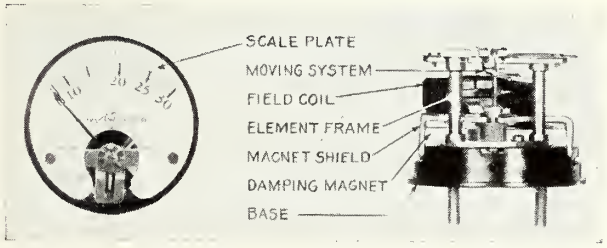

Fig. 5. Magnetic-vane type of mechanism of an a-c miniature instrument

In the operation of the thermo-ammeter, current (either a-c or d-c) flows through the heater wire and heats it in proportion to the square of the current. Two couple wires of dissimilar metals are connected to the center of the heater wire and thus are heated by the flow of current. This temperature rise of the dissimilar metals at the junction generates an emf which is a function of the current in the heater and which is indicated by the sensitive d-c moving element.

The deflection of the pointer varies as the square of the heater current, for which reason the scale distribution is laid out in accordance with the "squared" law. The low part of the scale is therefore congested, and the pointer indicates only one quarter of the linear distance for 50 per cent current. This distribution can be made more nearly linear by expanding the scale at the left, by so changing the pole-piece shape of the element as to concentrate the flux where the current strength is weak. The latter type of instrument is not as sturdy as the conventional type due to a decrease in spring torque to compensate for the increased air gap.

While rectifier-type instruments can be used effectively only at power and audio frequencies up to approximately 20,000 cycles, thermocouple instruments provide the most practical means of measuring current and voltage at higher frequencies. The increase in pointer indication of thermocouple instruments with increase of frequency for a given current value is due mainly to errors that result from effective resistance changes commonly expressed as "skin effect."

Thermocouple instruments will withstand only about 2¼ times normal load and should be used with care.

Class IV: Modified Soft-iron Vane Type of Mechanism for the Measurement of A-c Volts and Amperes

One of the commonly used a-c instrument elements is shown in **Fig. 5.** This magnetic-vane type of element is employed where the full-scale current is at least 5 milliamperes. The element is noted for its extreme sturdiness, reliability, and high overload capacity.

Briefly, this type of element is composed of a moving vane mounted on a nonmagnetic shaft that has a pointer and that is supported in suitable bearings. Adjacent to the vane is a fixed coil. When current flows in this coil, a magnetic field is set up which tends to pull the vane into the coil. The rate at which it is pulled is controlled by a flux distributor, and the movement is opposed by the torque of a control spring. The scale distribution approaches that of the square law, with the two-thirds electrical point at the mechanical center of the scale.

These instruments are used mainly at frequencies from 15 to 133 cycles and may also be used on d-c.

Design Improvements to Increase Usefulness

During recent years, many improvements have been made in the design of miniature instruments to increase their usefulness. Some of the better known achievements have been:

(1). Increased sensitivities
(2). Lighter weight moving systems
(3). More rapid pointer response
(4). Special scale distributions
(5). Higher frequency measurements
(6). Designs for special application—such as shock, vibrations, and varied climatic conditions.

Chrome steel or tungsten steel alloys, 36 per cent cobalt alloy, and the alnico alloys have been used for magnets, in the order given, to improve current sensitivities of the instruments. The low retentive and high coercive forces of the aluminum-nickel-cobalt alloys have made them most desirable for use in direct-current instruments[1] and as damping magnets in a-c instruments. Their high flux density in the air gap has made possible d-c miniature instruments having a full-scale sensitivity of ten microamperes, with

[1]"A New Measuring Instrument for Direct Current," by H. T. Faus and A. J. Corson, *Electrical Engineering*, vol. 59, p. 683, Dec. 1940.

sufficient sturdiness for laboratory use. Their use has also been extended to damping magnets for a-c magnetic damping systems.

Continued progress has been made in the reduction of wire sizes as used on direct-current instrument moving systems. Copper wire measuring 0.001 of an inch in diameter, and insulated with a suitable type of enamel, is in common use today. This wire that has a diameter about one-third that of the human hair has been of utmost aid in increasing current sensitivities since more turns can be wound on the armature in a given space.

Considerable progress has been made in reducing the weight and moment of inertia of the moving systems. Weights in the order of 0.20 grams are not uncommon today as compared with much higher weights previously.

Higher driving torque resulting from increased flux density in the magnet air gap and a larger number of turns on the armature winding have made higher opposing or control-spring torques possible. Lighter moving systems lower the bearing-friction torque. From these two conditions, the design quality or ability to stand abuse is derived. This measure of design quality is commonly referred to as the Mechanical Factor of Merit.[2]

Some instruments, notably volume-level and frequency-modulation indicators used in radio-broadcast monitors, are required to indicate relative strength of a tuned signal of audio frequency in comparison to a prescribed standard and must have definite dynamic characteristics. Rapid pointer response with controlled overswing is required to meet this application. Low moment of inertia and high-torque moving systems are used and result in the response of the pointer to reach normal position being as fast as 0.2 sec. as compared with one to two seconds normally, and in the pointer overswing being controlled to within 0.5 per cent on 3½-in. scale length instruments.

With the increased application of r-f ammeters to indicate wider ranges of current, the "expanded-scale" type of design has become more useful. As previously described, this expanded characteristic is obtained by concentrating the magnetic flux at the section where the current density is the weakest. Ranges of current in ratio of five to one may be read on this type of instrument.

The range of r-f current measurements has been increased to over 150 megacycles with improved accuracy by the use of a new low-impedance concentric-conductor design.[3] Full-wave copper-oxide rectifiers have been made with about one-fifth the capacitance of the conventional units to increase their range beyond the audio frequencies without undue frequency errors.

Recent requirements have made it necessary to make instruments that will withstand high shock and vibration. This has been possible by the use of special alloy large radius pivots in combination with stabilized moving systems having control springs made by special processes to have practically zero hysteresis or spring fatigue due to cold working caused from shock or constant vibration. Windings have been treated with special compounds and metals have been properly protected to enable instruments to operate in all kinds of climatic conditions, varying from the humid torrid atmosphere at the equator to the hot dry conditions in the desert and even to sub-zero temperatures in other parts of the world. Expansion factors have been studied, brittleness of materials has been considered, and tests under actual operating conditions have been made to prove the trustworthiness of design.

Critical Material Conservation

It is not generally realized that the average miniature indicating instrument, weighing less than a pound, contains over 40 materials. The majority of these materials has been designated by the War Production Board as being vital for the war effort. Such materials as aluminum, copper alloys, nickel, cobalt, cadmium, tin, sapphire, silk insulation, varnishes, shellac, plastics, solder, and mica must be conserved. This restriction has taxed the ingenuity of the engineers and laboratory personnel to find suitable substitutes in readily obtainable materials. Many substitutions have been made without loss of time or sacrifice of quality.

From the foregoing, it may be seen that a large range of d-c and a-c current and voltage measurements is possible by the proper applications of miniature instruments. With the increased use of indicating instruments in many new applications, it is hoped that new materials and smaller wire sizes will become available in order to further increase the range of sensitivity of these instruments. Such advances will obviously tend to broaden their application in the post-war period.

[2] "Mechanical Factor of Merit with Respect to Electrical Instruments," by J. H. Goss, General Electric Review, vol. 36, p. 188, April 1933.

[3] "Measurements at Radio Frequencies," by H. R. Meahl, P. C. Michel, M. W. Scheldorf, and T. M. Dickinson, *Electrical Engineering*, vol. 59, p. 654, Dec. 1940.

LIGHT METER . . .

The unique design of the light meter has made it adaptable to various types of special-purpose light-measuring devices

By C. L. DOWS
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General Electric Company

THE development of reliable light-sensitive cells, generally known as the blocking-layer dry-type, has resulted in a great variety of electrical-control applications and light-measuring instruments. The General Electric light-sensitive cell, which is the cell referred to in this article, is the result of many years of research and manufacturing experience and incorporates the desirable characteristics which such a cell should have. These include high output, long life, stability of output, etc.

Fig. 1. The older type of foot-candle meter was housed in a metal case

Fig. 2. The modern foot-candle meter is housed in a Textolite plastic case

Foot-candle Meter

In the consideration of light measurements, it should be remembered that all fundamental work of this kind is based on visual photometry; namely, the balancing of two spots for equal brightness. Accuracy, however, depends upon the knowledge and experience of trained photometrists, and while relatively high accuracy may be attained in the laboratory under controlled conditions, visual instruments for field use are less accurate, expensive, and cumbersome.

With the development of the foot-candle meter, although not better than 10 or 15 per cent accuracy was claimed for this device, it was possible for the first time to make practical field illumination measurements with less cumbersome equipment. The introduction of the meter can really be considered the beginning of an era of convenient and commercially accurate illumination instruments for field use.

Fig. 3. The light meter. Note that the light-sensitive cell is at right angles to the face of the scale

Approximately 10,000 foot-candle meters were put into use between the years 1917 and 1932, 7000 of these being housed in metal boxes and 3000 in the later designed Textolite plastic cases. These are shown in **Figs. 1** and **2.**

Light Meter

The first commercially available instrument which incorporated the cell was a light meter.[1] This little instrument, shown in **Fig. 3**, is familiar not only to everyone in the lighting profession, but is known to the executive, the superintendent, the maintenance man, the salesman, the schoolteacher, the student and even the parents in the home. Wherever it has been used (over 30,000 are now in use), whether by the lighting

(1)"The Light Meter and Its Uses," by C. L. Dows and C. J. Allen, *Trans. Illuminating Engineering Society*, vol. 31, no. 7, p. 675, July 1936.

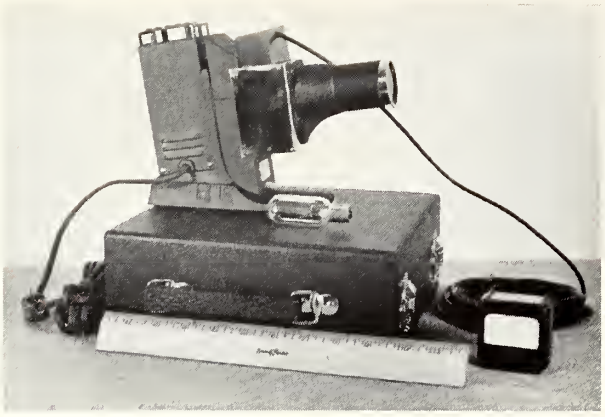


Fig. 4. The projection light meter described in the accompanying text

engineer for laying out and checking up a lighting installation, or in the hands of the school child, who has taken it home to check up his study light, its use has effectively emphasized the value of good lighting and has contributed a big share in the art of better lighting practice.

There are a number of advantages to this particular design of light meter. It measures only 2¼ inches square by 1⅜ inches thick and weighs only seven ounces. The scale face is placed at right angles to the light-sensitive cell so as to permit reading of the instrument without shading of the cell by the observer. The standard instrument has a full-scale reading of 0–75 foot-candles and, when used with a 10-to-1 multiplier, reads up to 750 foot-candles full scale. All light meters are calibrated at two points, namely 20 foot-candles and 60 foot-candles, with direct light at a color temperature of 2700 K. The instrument is rated for an accuracy of ±7.5 per cent due to manufacturing tolerances in the cell-microammeter combination but under certain conditions a greater accuracy may be obtained.(2)

Fig. 5. The light meter and the attachment which converts it into a voltage indicator

Because of its unique design, this light meter has been adapted in a number of modified forms to other light-measuring devices.

Projection Light Meter

One of the first adaptations of the light meter was called the projection light meter. This instrument is shown in **Fig. 4**. The pointer of the microammeter is inverted and swings over a transparent scale in the form of a lantern slide. The scale is the exact duplicate of the light meter scale. The mechanism is completely enclosed to make it dust-tight and becomes, in effect, a lantern slide when adapted with the proper lens system to a standard projector. The light-sensitive cell is mounted in a dummy light-meter case on the end of a flexible cord. This unit has been found exceedingly useful for classroom and demonstration work.

Fig. 6. The modern exposure meter

Voltage Indicator

An attachment to be used with the standard light meter, which converts it into the voltage indicator,(3) is shown in **Fig. 5**. The attachment consists of a cylindrical hood, a properly selected incandescent lamp to operate on the standard 115-volt circuit and an attachment cord and plug. The device is calibrated by adjusting the lamp so that the light meter reads 20 foot-candles when the voltage is exactly 115 volts. Other voltages between 100 and 130 can be readily determined from a conversion scale pasted around the top of the cylindrical hood, showing the relationship between volts and foot-candles. In order to reduce the light output of the adjustable lamp to the range of the light meter, a standard 10-to-1 multiplier is clipped over the top of the light meter.

Exposure Meter

Both the original General Electric exposure meter and the more recently improved model have basically the design of the light meter. These instruments have the same simplicity, sensitivity, ruggedness, and

(2)"Illumination Measurements with Light-sensitive Cells," by C. L. Dows, *Illuminating Engineering*, vol. 37, no. 2, p. 103, February 1942.
(3)"Voltage Indicator for Use with Light Meter," *Magazine of Light*, vol. 6, no. 4, p. 2, April 1937.

Fig. 7. Measuring the reflection factor of a wall with a light-sensitive cell reflectometer

reliability that have always characterized this design. The exposure meter is shown in **Fig. 6.**

Light-sensitive Cell Reflectometer

The light-sensitive cell reflectometer[4] is an adaptation of the Taylor Reflectometer. In it a light meter has been substituted for the visual equipment originally employed and another sphere has been added to make possible the measurement of transmission as well as reflection.

This instrument makes possible the rapid measurement not only of reflection factors but transmission factors of test samples almost as fast as they can be inserted. In **Fig. 7** the instrument is shown being used to measure the reflection factor of a wall, and in **Fig. 8** it is being used for the measurement of transmission by inserting the sample between the two spheres.

Fig. 8. The light-sensitive cell reflectometer can also be used to measure transmission factor. The sample is inserted between the two spheres

L-H Brightness Meter

As in the case of other photometric measurements the most accurate measurements of brightness (foot-lamberts or candles per square inch) are made visually. A very excellent portable brightness meter, which operates on the visual principle, is known as the Luckiesh-Taylor Brightness Meter. A simpler device, however, making use of the light meter, and which meets most of the needs arising in lighting practice, is known as the L-H Brightness Meter.[5] The light meter can be slipped out of the brightness meter case and used for conventional work or it can be stored in place in the brightness meter.

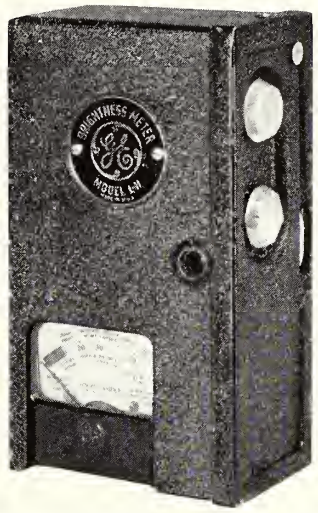


Fig. 9. The model L-H Brightness Meter. The light meter can be slipped out of the case for conventional work

The brightness meter, shown in **Fig. 9**, consists essentially of a miniature comparison lamp operated from two dry cells by means of a rheostat, two sets of filters for obtaining suitable combinations for the range of brightness to be measured, an eye-piece for viewing the object to be measured, and a standard light meter. After selecting the proper filters which are on rotating disks, the photometric balance is made by turning the upper knob shown on the side, which varies the current supplied to the miniature lamp. The light meter is directly affected by the light output of the comparison lamp and, when a balance has been obtained, brightness in foot-lamberts is read directly on the light-meter scale. It will be observed that this instrument combines both the light-meter principle and the principle of photometric balance.

Ultraviolet Meter for Germicidal Lamps

In order to measure the radiant energy in the ultraviolet region near 2537 angstroms, a simple and

(4) "A Light-sensitive Cell Reflectometer," by G. R. Baumgartner, General Electric Review, vol. 40, p. 525, November 1937.
(5) "A Simple Brightness Meter," by M. Luckiesh and L. L. Holladay, *Magazine of Light*, vol. 8, no. 2, p. 4, March 10, 1939.

effective attachment for the light meter has been developed.[6] It consists of a metal frame holding together plates of glass and fused quartz with a thin layer of a fluorescent phosphor between them. This combination is placed over the light-sensitive cell as shown in **Fig. 10.**

When the device is attached to a light meter with the quartz plate exposed, the ultraviolet energy causes the phosphor to fluoresce, and this in turn produces a deflection of the light meter. A part of the deflection is due to energy transmitted by the entire attachment, quartz, phosphor, and glass. In order to compensate for this, the attachment is turned over, so that the glass is exposed. Since the glass does not transmit any of the 2537 angstrom energy, the phosphor no longer fluoresces appreciably and the meter indicates only the energy transmitted by the glass, quartz, and phosphor. Thus, the difference in the reading under the two conditions is a direct measure of the intensity of the germicidal energy producing the fluorescence.

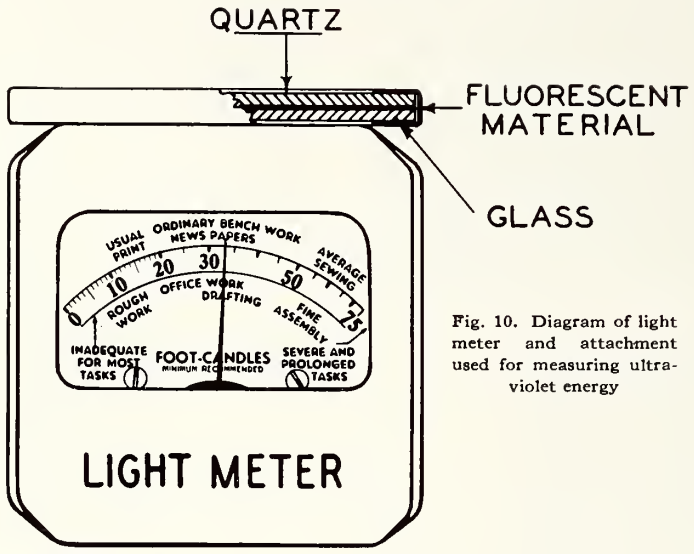


Fig. 10. Diagram of light meter and attachment used for measuring ultraviolet energy

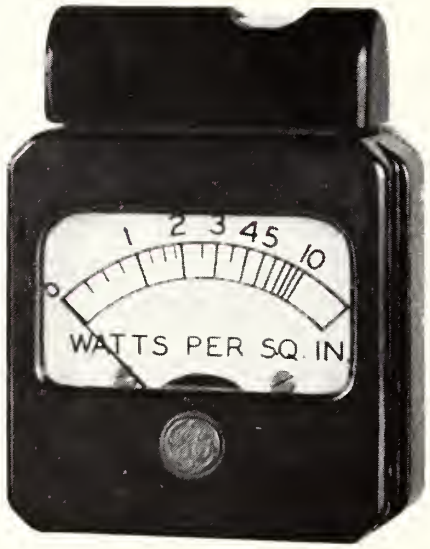


Fig. 11. The radiation thermocouple for measuring radiant energy of wavelengths between 3000 and 35,000 angstrom units

Fig. 12. Another meter for the measurement of radiant energy

Fig. 13. A meter for making temperature measurements

Meter for Temperature and Radiation Measurements

The new "drying" lamps used for many industrial heating jobs require instruments for measuring the concentration of radiant energy and the temperature of the work as it is exposed to that radiation. For simple portable instruments that can be taken into the field, various forms of the light meter have been found very acceptable. Such instruments have proved sturdy, compact, and convenient to use.

The instrument shown in **Fig. 11** is a light meter

[6] "Ultraviolet Meter for Germicidal Lamps," by Matthew Luckiesh and A. H. Taylor, *The Review of Scientific Instruments*, vol. 11, no. 3, p. 110, March 1940.

equipped with a more sensitive moving element and a vacuum thermocouple in place of a light-sensitive cell. The radiation thermocouple is equally responsive to radiant energy of wavelengths between 3000 and 35,000 angstrom units.

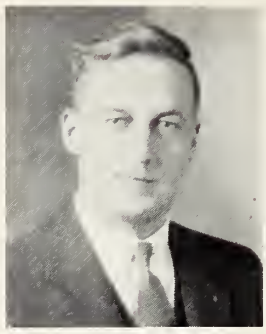
Another adaptation consists of a light meter with a special low-resistance element and with terminals on the top in place of the light-sensitive cell. An arbitrary linear 0–100 scale has been found very useful. A series of curves allows the user to measure the concentration of radiant energy or the temperature of an article using either the vacuum thermocouple as shown in **Fig. 12** or a thermocouple such as shown in **Fig. 13**. External shunts can be connected to the meter to extend the range if desired. These meters have also been built as projection meters, so that large groups can see the results of measurements.

Other Applications

In addition to the instruments described, the light meter has been incorporated into a number of other types of laboratory and portable equipment. The simplicity of design in combining the cell and the microammeter makes it easily adaptable to many applications. Higher sensitivity than is afforded by the standard light meter can be obtained by use of a more sensitive microammeter within the standard light-meter case.

INKLESS RECORDING . . .

Sensitive and reliable, this versatile inkless recording system can be employed to measure practically any electrical quantity



By P. E. TWISS
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ONE of the objectives of modern instrument design has been to develop an alternative to the pen-and-ink system of recording on a chart the movements of electrical measuring elements. Naturally, any alternative should have higher sensitivity, improved reliability, and lower cost and weight.

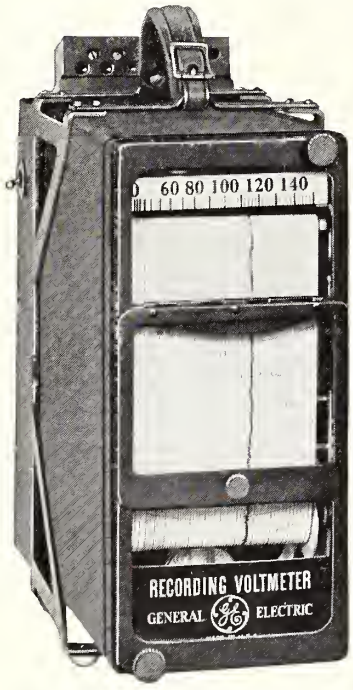

Fig. 1. The inkless recording voltmeter described in the accompanying text

Development

During the course of development, many recording methods were tried using such marking media as carbon paper, carbon rolls, chemically treated paper, etc. In the search for the most practical inkless recording system, it became apparent that the intermittent marking or dotting system had not been utilized to the fullest extent. With the exception of the continuity of record, this marking system appeared to have very definite advantages over the use of liquid ink.

An intensive study was made with a view of obtaining rates of dotting sufficiently high to obtain a continuous record for all practical purposes. Although this system had been used for many years, apparently no successful attempts had been made to produce an instrument having a dotting rate much in excess of one dot per minute. It was felt that if dotting rates in the order of one per second or faster could be obtained, the record on all normal chart speeds would be sufficiently continuous to be satisfactory for commercial circuit analysis.

As a result of tests made on various instruments, it was found that there was a definite relationship between the rate of dotting, the responsiveness, and the torque of the electrical element. For instance, assuming an instrument with a response of one second, a dotting rate of one per second could be imposed upon the moving system of an element in the indicating-instrument group of torque values, while considerably higher dotting rates could be successfully used on instruments of the same response but of greater torque values. The reason for this is apparent when it is considered that any striking mechanism must of necessity deflect the moving system slightly, and the element should, therefore, be given time to recover from this deflection before the next blow. Also, the greater the torque of the instrument, the less the system is deflected by the striking mechanism. It is, of course, necessary that a high order of mechanical precision be maintained on all moving parts to reduce to a minimum the amount of deflection given the pointer by this mechanism.

Operation

In **Fig. 1** is shown a conventional high-torque recorder, originally designed for use with liquid ink, but now equipped with an inkless recording unit in place of the usual capillary pen and inkwell. This type of instrument has a response of one second and a full-scale torque of 230 millimeter grams. With this high-torque condition, it was found that a dotting rate of four per second could be used without causing the element to deviate from its true indicating position. In **Fig. 2** is shown a similar recorder with the cover removed to expose the inkless unit mounted at the top of the instrument. A metal stylus replaces the pen, and the back end of the stylus is deflected downward by means of a four-point cam, driven by a Telechron motor at 60 rpm. This causes the front end of the stylus to rise approximately ½ in. above the chart surface and fall by its own weight upon a typewriter ribbon stretched across the top surface of the chart,

thus leaving a series of dots on the face of the chart. The rotating cam is located over the center of rotation of the moving element, thus reducing to a minimum any tendency to deflect the pointer sideways, or to impose any appreciable frictional load upon the moving system.

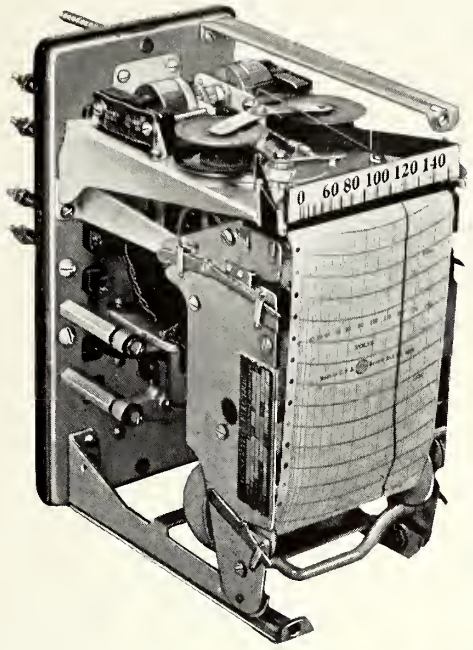

Fig. 2. The inkless recording voltmeter with cover removed

Advantages

The typewriter ribbon on this recorder is driven by a second Telechron motor at such a rate that the ribbon spools need reversal but once a month. The complete device is a self-contained unit that may be included as an optional feature on recording instruments for measuring voltage, current, power, power factor, frequency, or practically any other electrical quantity. This device offers a solution to many problems associated with the use of liquid ink, such as freezing, evaporation, spillage, and limited length of operation before reservicing. Thus, with a chart speed of one inch per hour, a high degree of reliability of operation may be assured for a complete month's time with but a single servicing. For use with portable instruments, such a unit offers many conveniences. It may be transported in a car or truck without danger of ink spillage and is immediately ready for service as soon as it is connected to the power supply.

The type of record obtained with one of these instruments operating as a voltmeter is essentially continuous and as good in every respect as the conventional ink record. This same device applied to an ammeter on a highly fluctuating load will result in a series of dots during rapid pen movements, but a study of such a record as compared with an ink record shows that, as indicated in **Fig. 3**, somewhat more information can be obtained by a careful analysis of the dotting record than is possible with the ink type. For instance, it is possible to estimate the duration of a short surge if such information is of value to the user.

Consider a conventional ink-type recorder with a chart speed of three inches per hour. Upon the occurrence of a surge of one-second duration, which is within the response time of the instrument to record, the chart would travel 0.0016 in. in the two seconds required for the pen to deflect and return to its original position. As the width of the inked line is seldom less than 0.020 in., the chart would show only a single line for the two pen movements. It would be necessary to step up the chart speed at least 60 times to show a spacing between the inked lines so that any idea of time measurement could be obtained. With a dotting rate of four dots per second, the intermittent marking recorder would show eight dots for this deflection, indicating that a load change occurred lasting one second, with another second required for the element to return to its original position. Thus under steady load conditions, the record would appear as a continuous line of 4800 overlapping dots per inch, while the surge (assuming one-inch deflection) would take place 1200 times faster, one inch per second and four dots per inch,

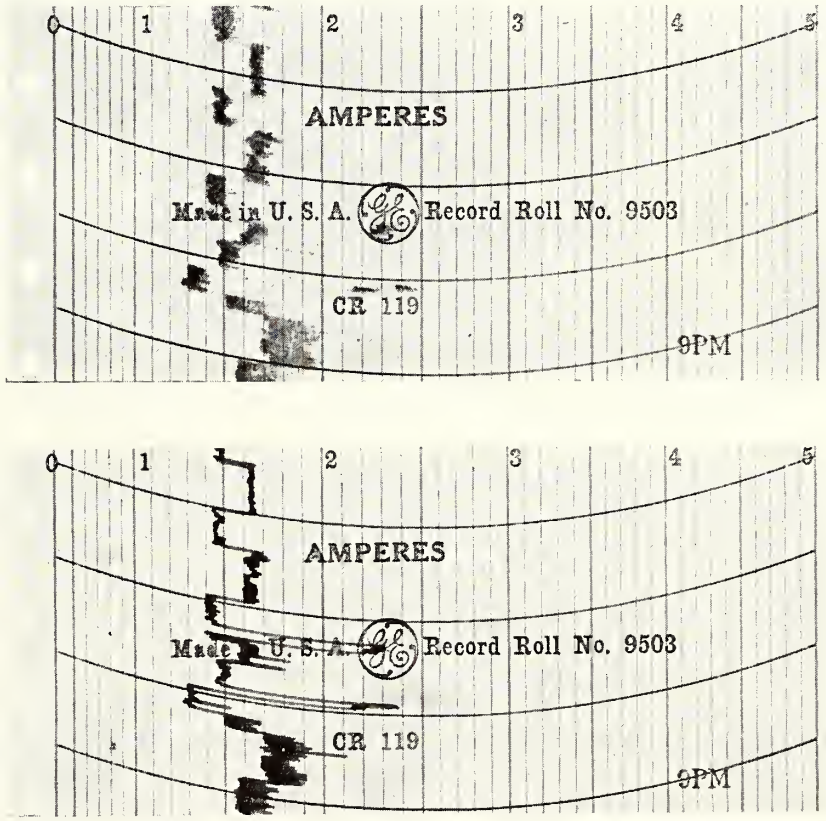

Fig. 3. Comparison of records taken with an inkless (*top*) and a conventional type of ink recorder on an extremely variable-current circuit

permitting accurate estimates of short-time deflections at economical chart speeds.

Another advantage, previously mentioned and which will be discussed later for special applications, is the ability of the inkless recorder to operate under highly fluctuating loads, at extremely low chart

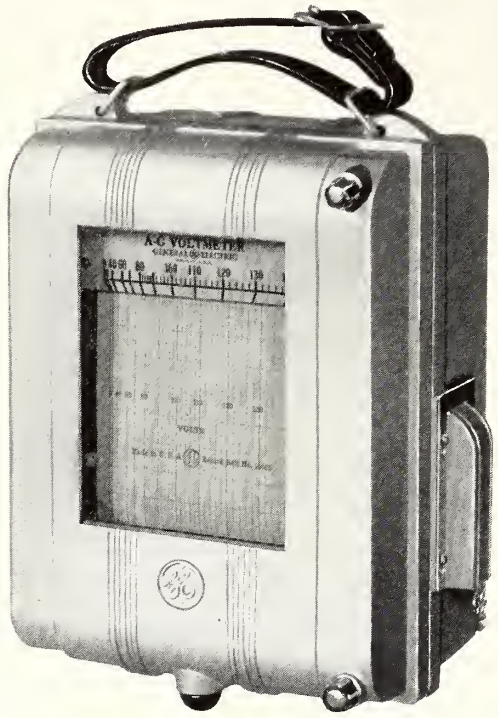

Fig. 4. A portable, weatherproof inkless recording a-c voltmeter

speeds, without danger of "painting" the chart with liquid ink. On the other hand, if a pen-and-ink recorder were operated under such conditions, ink might not dry fast enough to prevent blotting during the rerolling process, thus obscuring the record.

In the direct-marking system necessary for use with liquid ink, a small but definite frictional load is imposed upon the moving system due to the contact of the pen on the chart. It is necessary that the torque of the electrical element be sufficiently high so that the percentage of error due to such friction is negligible. With the intermittent marking system, such high-element torques are not necessary, and material reductions in instrument size and cost have been made by the use of small electrical elements of the indicating type. The type of inkless recorder shown in **Fig. 4** weighs but 11 pounds and utilizes a small lightweight element having a full-scale torque of one millimeter gram, or less than 1/200 of the torque of the larger instrument. In this design, dotting is accomplished by clamping the pointer between a fixed platen located underneath the scaleplate with a striker bar operated once a second by a Telechron motor. As this type of element has the same response as the larger instrument, but much lower torque value, the frequency of dotting cannot exceed the normal response of the moving system without deflecting the pointer appreciably. However, this rate is sufficient to obtain a continuous appearance of voltage records and the operation of ammeters on fluctuating loads is quite satisfactory, as shown by the charts in **Figs. 5** and **6** which were taken with both ink and inkless types of instruments on the same circuit. **Fig. 6** shows a painted condition previously mentioned, demonstrating clearly the advantage of the intermittent type of recorder.

In **Fig. 7** is shown a diagrammatic view of the arrangement of the striker bar, pointer, chart, ribbon and platen, the entire design of which allows maximum protection to the delicate moving system of the element and maximum convenience in servicing charts and ribbons.

The power required to operate the ammeter is so low (one volt-ampere) that it is possible to use split-core current transformers interchangeably (200 amp and above) without the special calibration necessary in the case of ink-type-recorders of higher power requirements. Direct-current ammeters are available in

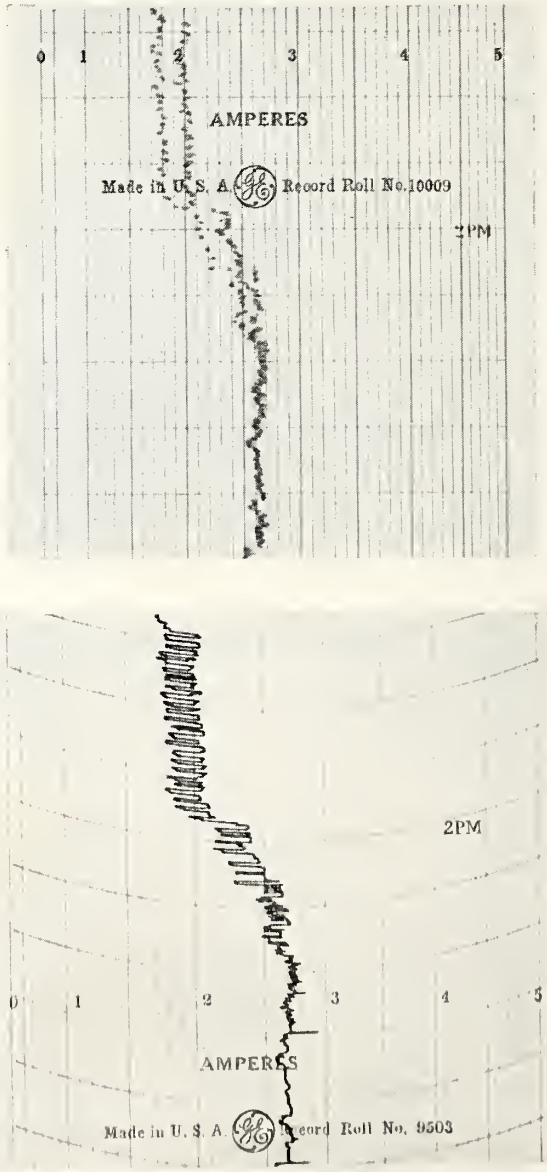

Fig. 5. Current record. Note that the inkless record (*top*) gives clear indication of maximum and minimum current values on fluctuating load

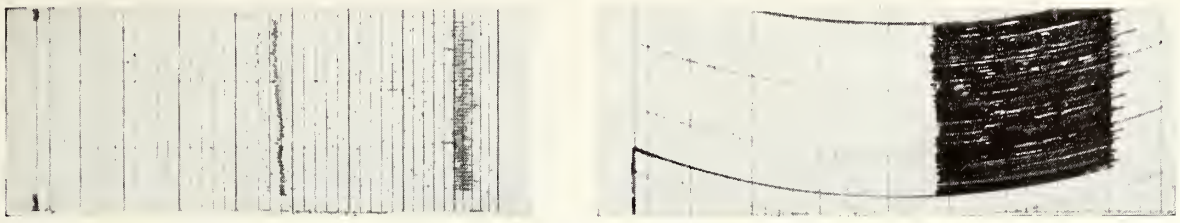

Fig. 6. Current record of extremely fluctuating load. The ink recorder has painted the chart (*right*), thus giving little useful information, while the inkless record shows clearly that there were two normal operating current values and allows a detailed analysis

capacities as low as 125 microamperes, whereas the direct-marking type of recording instrument is limited to a minimum of one milliampere. New applications are therefore made possible with this type of instrument which previously required the use of the more expensive photoelectric recorder.

Previous reference was made to the use of these inkless recorders at extremely low chart speeds. Studies of power surveys on distribution systems prove that short duration tests of a week do not always show the complete picture. Tests covering a longer period are desirable, but a month's operation of a recorder at a chart speed of one inch per hour (the lowest speed generally used for strip-chart recorders) results in a chart 65 feet long, which is difficult to analyze conveniently.

A well-known authority on distribution systems makes use of a chart speed of one inch per day, using an inkless recorder which condenses the results of a month's operation on a 30-in. chart length. In this manner, peaks and valleys are amplified and readily associated with daily periods, thus permitting more accurate analysis of circuit conditions at a minimum cost. Respecting the application he has stated:[1]

"The availability of recording voltmeters and ammeters, having a chart speed of one inch per day, now makes it possible to take long-time measurements of voltage and amperes simultaneously at several strategic places on the system with a small investment in equipment and with little labor. Thirty-inch charts can be quickly interpreted and readily filed for reference. These records will give a more comprehensive knowledge of what is going on in the system and make possible a more intelligent and

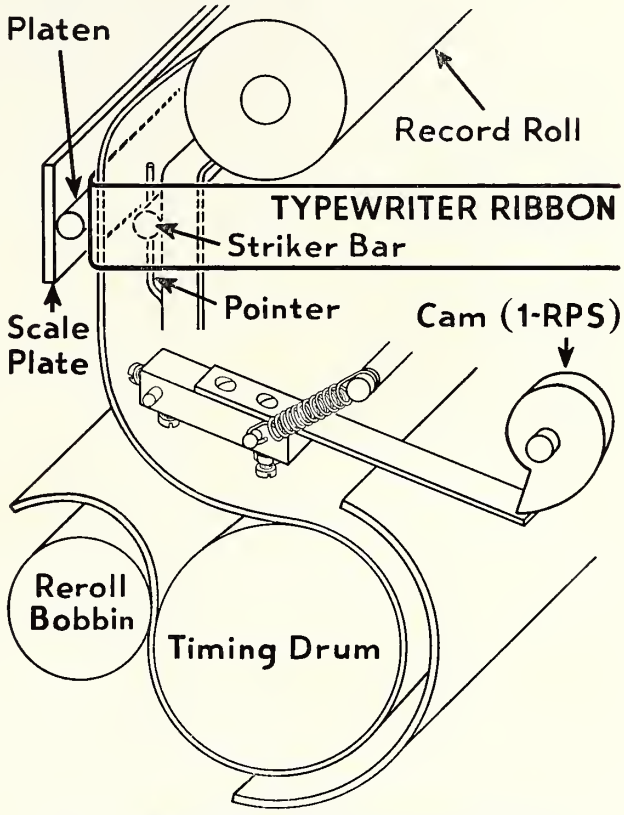

Fig. 7. Diagrammatic view of chart and marking mechanism of the inkless recorder

beneficial use of spot and seven-day tests, in addition to being valuable guides in system planning.

"It's worth some trouble and expense just to *know*, by measurement, that all is well when we expect it to be. It's worth more when we are uncertain, and is as good as a cash dividend when we find bad conditions we did not expect. When you measure, then you know. When you know, then your engineering and operation rest upon a scientific foundation."

[1]"D. K. Blake's Comments," *Distribution*, October 1941.

DEMAND METERS . . .

And totalizing relays: Their service in measuring nonelectrical as well as electrical quantities

By H. M. WITHEROW and E. J. BOLAND
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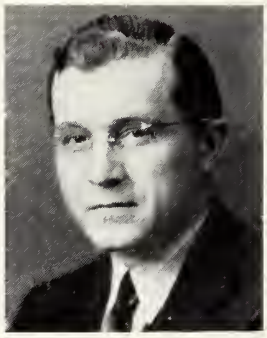
H. M. Witherow

DEMAND meters are conventionally applied as companions to watthour meters. Their use provides a factor which, broadly speaking, represents the investment necessary in generating and distribution equipment to meet instantly the demand of consumers for service within wide limits of power requirements.

A given rate schedule usually defines the unit in which demand is to be measured, such as kilowatts, kilovars, etc., but the unit used is likely to differ with different central-station companies. The unit of demand must be a compromise between the cost factors that the demand charge is intended to represent and the facility with which the factors can be measured.



E. J. Boland

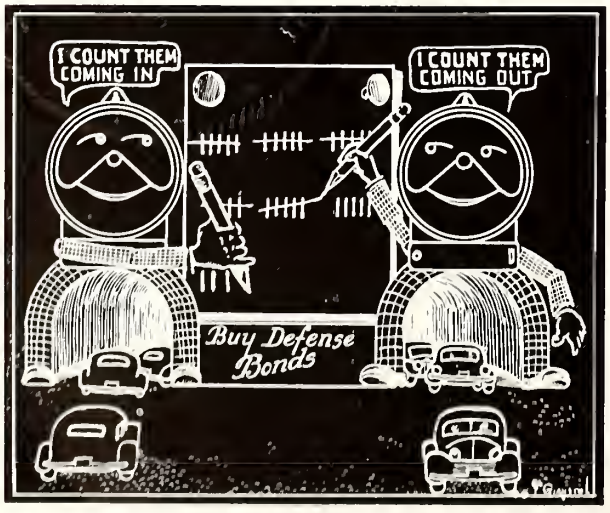
Demand-measuring devices fall into two general classes; namely, integrating demand meters (block-interval type) and lagged demand meters. Each of these possesses characteristics which are of distinct benefit in its usual field of application, but the block-interval types are fundamentally more readily applicable to the solution of problems of the class considered in this article.

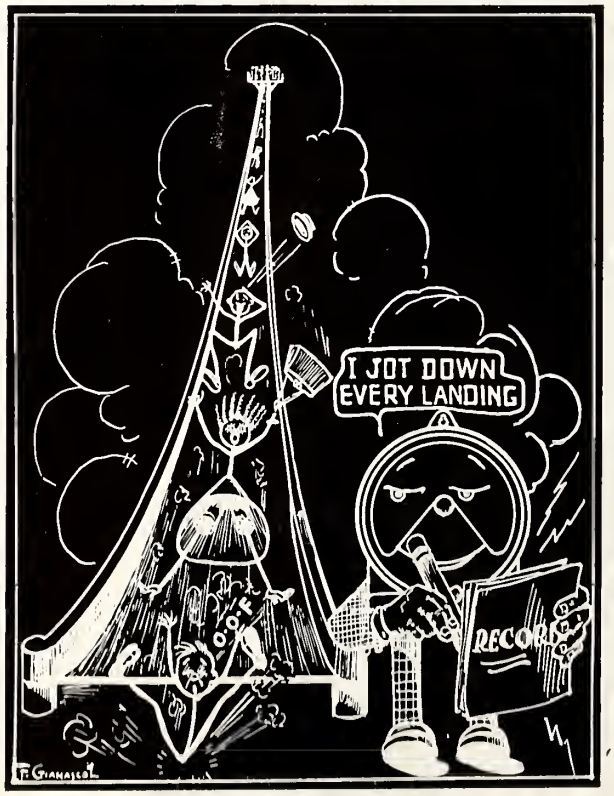
The integrating demand meter measures the arithmetic average of the varying load (in kilowatts or kilovars, etc.) during a prescribed interval of time. In accordance with definitions, the average value thus determined is the demand. In other words, if the demand is measured in units of kilowatts then the kilowatt demand of the time interval is that kilowatt

Blackboard reminders that:

(Right)
Demand meters can be used to determine the rate at which objects reach, or pass, a given point

(Below)
The number of vehicles in a tunnel at any time can be indicated by an additive-subtractive demand-totalizing relay





value which if maintained constant during the time interval would result in the same kilowatt-hours as the actual integration of kilowatt-hours during the time interval.

In contrast, the lagged demand meters measure the logarithmic average of the varying kilowatts during a specified interval of time.

Integrating Demand Meters

Considering only the integrating demand meter, kilowatt demand for a given interval of time is simply the integrated kilowatt-hours divided by the time expressed in hours. Thus, from a measuring standpoint, the meter may be looked upon as a mechanical counting device attached to or operated in conjunction with a watthour meter for the purpose of "setting off" the number of kilowatt-hours integrated for each designated interval of time. Therefore, if the demand is to be measured in some unit other than kilowatts, such as kilovars, the watthour meter must be changed to integrate that quantity.

When the integrating demand meter is of the impulse-operated classification, the associated watthour meter is equipped with a suitable contact mechanism which produces an impulse for a predetermined number of integrated kilowatt-hours. These impulses are added up for each interval of time by the demand meter. The recording types make a record of the addition for each interval but the indicating meters will show only the highest (maximum) addition during any one interval.

Totalizing Relays

As the demand-metering problems become more complicated, increased use is made of demand measurements which follow the principle of producing, transmitting, and integrating electric impulses. In the relatively simple example of determining the totalized demand of an installation which receives service through two connections (two watthour meters) the watthour meters may be equipped with suitable contact devices to produce electric impulses and these impulses in turn may be added in a so-called totalizing relay and retransmitted to an impulse-operated demand meter. By proper selection and cascading of relays, the range of totalization can be expanded to practically any number of circuits, for the straight addition of all circuits or combinations of additions and subtractions.

Occasionally, the problem is one of determining the total kilowatt-hours, but not kilowatt demand, of an interconnection where the charge per kilowatt-hour is one value for one direction of net power flow and some other value for the opposite direction. Demand-metering equipment is then used not for the purpose of measuring demand but rather to determine net total kilowatt-hours in one or both directions of power flow. This problem, however, must not be confused with the simple addition of kilowatt-hours for a group of circuits or feeders, for which there is at present no easier and more accurate method than the use of separate watthour meters in each circuit and a simple arithmetic addition of the readings of the several meters to determine the total kilowatt-hours.

The scope of demand metering may be appreciated from the fact that standard equipment is used from a single-circuit installation to the totalization of more than 100 circuits, and from as little as five kilowatts to more than 100,000 kilowatts demand.

Measuring Other Than Electrical Quantities

While demand meters are normally associated with the measurement of electrical quantities, such as kilowatts, kilovars, kilovoltamperes, etc., their application is not confined to such quantities. Impulse-operated meters are essentially mechanical adding machines and therefore they are useful also for measuring other than electrical units. Whenever the units to be integrated can be represented by electric impulses, the standard demand meters lend themselves to automatic addition over the standard intervals of 15, 30, or 60 min.

For example, by providing an integrating gas meter with a contact device to produce impulses for a prescribed value of cubic feet of gas, the standard impulse-operated demand meter can be used as a gas-demand meter. Or, the problem may be one of determining the rate (the average for the interval) at which manufactured articles pass a given point on an assembly line.

In a similar way, it is possible to use totalizing relays, which are essentially multicircuit adding machines, when the problem is more complicated. As an example, in a traffic tunnel for vehicles the problem of ventilation and traffic regulation may make it desirable to know how many vehicles there are at any time in the tunnel or in a section of it. By simply producing "positive" impulses for entering and "negative" impulses for leaving vehicles, the totalizing cyclometer counter on a differential (additive-subtractive) totalizing relay will give a running record of the total vehicles in the tunnel, or in a particular section, at any time.

These few examples will undoubtedly suggest other applications for standard devices. The requisites are few and can generally be complied with. The units to be measured must in some way be expressed in electric impulses. Next the impulse rate must not be excessive, not more than one impulse per second, and, finally, if it is desired to obtain a graphic or printed record from a demand meter, the total number of impulses for the interval must be within the full-scale capacity of the meter.

The advantages of using standard devices are obvious. Therefore, emphasis is placed on the fact that standard demand meters function to integrate automatically over standard intervals of 15, 30, or 60 min. Only through special arrangements and by using additional equipment can the integrating interval be made adjustable and controllable from manual operation.

INSTRUMENT TRANSFORMERS

The new insulation level requirements of power-line apparatus and how they have been met in the dry-type instrument transformers

By W. K. DICKINSON
Instrument Transformer Engineering Department
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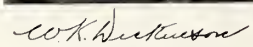

DURING the past two decades a great amount of time and effort has been spent in the study of overvoltages and their affect upon apparatus connected in electric circuits. The knowledge thus obtained has been used to establish new requirements for insulation tests and these new requirements have in turn necessitated changes in the art of building electric equipment.

Instrument transformers are practically indispensable, not only for accurate measurements but also for the proper operation of protective devices. Therefore, it is highly important that the insulation level of instrument transformers be established on the same basis as that of other equipment to insure reliable service.

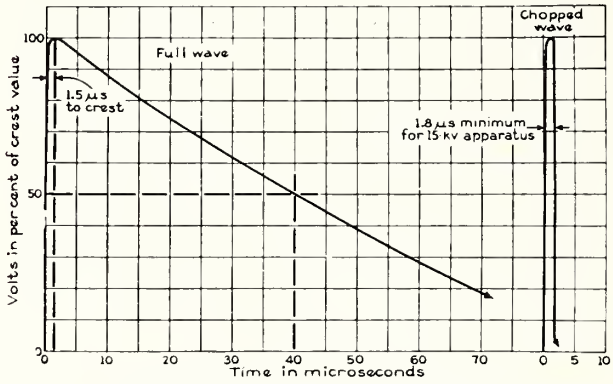

Fig. 1. Impulse wave shapes that have been adopted as standard for determining insulation rating

For many years the A.I.E.E. standardization rules for insulation of instrument transformers were thought to be adequate. Those rules were far less extensive than the present rules, and the insulation test requirements were covered by the following:

Current Transformers: The primary test voltage of current transformers shall be 2¼ times the rated voltage plus 2000 volts.

Potential Transformers: The primary test voltage of potential transformers shall be twice the rated voltage plus 1000 volts. Also, the test voltage between the turns shall be made by applying between the terminals of one winding a voltage twice the normal voltage developed in the winding corresponding to voltages being induced in the free winding.

Based largely upon experience, it became the practice of the General Electric Company to build into its transformers greater insulation strength than was required to pass these tests. However, transformers which appeared to have adequate insulation sometimes failed.

With the advent of the cathode-ray oscillograph, which made it possible to measure the speed and shape of transient impulses in terms of microseconds, an entirely new field of investigation and development was opened. It was found that the dielectric strength of insulating materials varied with the shape and duration of the transient overvoltages, or "impulses" as they soon came to be called. This apparently accounted for the failure of apparatus which seemed to have adequate insulation as based on 60-cycle tests. The need immediately became apparent for the answer to the questions: "What are the variations in the wave shape and what is the magnitude of the transient overvoltages resulting from lightning, switching, or other causes? What test levels should be established? What modifications in transformer design are required to meet these tests and insure satisfactory service?"

Because of the wide variations found to occur in the magnitude and duration of these overvoltages, it was evident that there really was no "typical lightning wave." However, it was essential to have some one wave as a reference basis on which to determine the insulation rating or insulation level, and to serve as a standard for comparison. The wave shape finally agreed upon is known as the "1.5×40 microsecond wave." The first number in the designation represents the time from start to crest and the second number represents the time from start to the 50 per cent crest point on the tail of the wave. The standard wave is illustrated in **Fig. 1**.

The question "What should be the magnitude of impulse tests for apparatus intended for use on each circuit voltage?" proved to be exceptionally difficult to answer. The general conclusion from a vast amount of data is that the lightning overvoltage occurring on any circuit is limited by the flashover voltage of the line insulation used on that circuit. Therefore, it was apparent that, without protection, apparatus could not economically be designed to withstand direct or nearly direct lightning strokes.

TABLE I

PREFERRED RATIOS, STANDARD INSULATION CLASSES, AND DIELECTRIC TESTS FOR POTENTIAL TRANSFORMERS

Insulation Class (Nameplate Rating)	Preferred Ratio	RATED VOLTAGE		NORMAL CIRCUIT VOLTAGE ON WHICH TRANSFORMERS MAY BE USED		DIELECTRIC TESTS			
						Low Frequency	Impulse		
							Chopped Wave		Full Wave
		Secondary Winding	Primary Winding (Nameplate Rating)	When △ Connected	When Y Connected			Min. Time to Flashover	
(Kv)		(Volts)	(Volts)	(Volts)	(Volts)	(Kv rms)	(Kv Crest)	(μ Sec.)	(Kv Crest)
(a)	(b)	(b)		(a) (c)	(a) (d) (e)	(f)	(f)	(f)	(f)
1.2	1:1	120	120	120	208	10	36	1.0	30
	2:1	120	240	240	416	10	36	1.0	30
	4:1	120	480	480	832	10	36	1.0	30
	5:1	120	600	600	1040	10	36	1.0	30
2.5	20:1	120	2400	2400	2400	15	54	1.25	45
5.0	20:1	120	2400/4160Y	2400	4160	19	69	1.5	60
	40:1	120	4800	4800	4800	19	69	1.5	60
8.66	35:1	120	4200/7280Y	4200	7200	26	88	1.6	75
	40:1	120	4800/8320Y	4800	8320	26	88	1.6	75
	60:1	120	7200	7200	7200	26	88	1.6	75
15 L	60:1	120	7200/12480Y	7200	12000	34	110	1.8	95
	70:1	120	8400/14560Y	8400	14400	34	110	1.8	95
	100:1	120	12000	12000	12000	34	110	1.8	95
	120:1	120	14400	14400	14400	34	110	1.8	95
15 H	60:1	120	7200/12480Y	7200	12000	34	130	2.0	110
	70:1	120	8400/14560Y	8400	14400	34	130	2.0	110
	100:1	120	12000	12000	12000	34	130	2.0	110
	120:1	120	14400	14400	14400	34	130	2.0	110
25	200/115:1	69.3/120	13800/24000Y	—	24000	50	175	3.0	150
	200:1	120	24000	24000	24000	50	175	3.0	150
34.5	300/173:1	66.4/115	19900/24500Y	—	34500	70	230	3.0	200
	300:1	115	34500	34500	34500	70	230	3.0	200
46	400/231:1	66.4/115	26600/46000Y	—	46000	95	290	3.0	250
	400:1	115	46000	46000	46000				
69	600/346:1	66.4/115	39800/69000Y	—	69000	140	400	3.0	350
	600:1	115	69000	69000	69000	140	400	3.0	350
92	800/462:1	66.4/115	53100/92000Y	—	92000	185	520	3.0	450
	800:1	115	92000	92000	92000	185	520	3.0	450
115	1000/577:1	66.4/115	66400/115000Y	—	115000	230	630	3.0	550
	1000:1	115	115000	115000	115000	230	630	3.0	550
138	1200/693:1	66.4/115	79700/138000Y	—	138000	275	750	3.0	650
	1200:1	115	138000	138000	138000	275	750	3.0	650
161	1400/809:1	66.4/115	93000/161000Y	—	161000	325	865	3.0	750
	1400:1	115	161000	161000	161000	325	865	3.0	750
196	1700/982:1	66.4/115	113000/196000Y	—	196000	395	1035	3.0	900
	1700:1	115	196000	196000	196000	395	1035	3.0	900
230	2000/1155:1	66.4/115	133000/230000Y	—	230000	460	1210	3.0	1050
	2000:1	115	230000	230000	230000	460	1210	3.0	1050
287	2500/1444:1	66.4/115	166000/287000Y	—	287000	575	1500	3.0	1300
	2500:1	115	287000	287000	287000	575	1500	3.0	1300
345	3000/1733:1	66.4/115	199000/345000Y	—	345000	690	1785	3.0	1550
	3000:1	115	345000	345000	345000	690	1785	3.0	1550

NOTES:

(a) Intermediate voltage ratings are placed in the next higher insulation class unless otherwise specified.

(b) Two types of potential transformers are available in insulation classes 25 kv and above. One type is for primary line-to-neutral connection and is provided with a tapped secondary winding, or with two secondary windings, to make available nominal 115 or 120 secondary volts when connected Y or △. These transformers are designated in Column 2 by the double ratio, for example 200/115:1. The other type is for primary line-to-line connection to make available 115 or 120 secondary volts from each transformer. These transformers are designated in Column 2 by the single ratio, for example 200:1.

(c) When transformer apparatus is used on a △-connected system which operates with one phase grounded, special consideration should be given to the selection of the insulation class.

(d) Y-connected transformers for operation on a system whose neutral is solidly grounded, or grounded through an impedance, may have reduced insulation at the neutral as specified in 2.031.

(e) All potential transformers for Y-connection on a 3-phase 3-wire ungrounded or impedance grounded system (or on a 4-wire system where the ground may be disconnected during a line-to-ground fault) should be designed to have magnetic induction low enough to enable them to operate continuously at line-to-line voltage.

(f) The secondary windings of instrument transformer shall withstand low-frequency test of 2500 volts to ground and normally grounded core and other metal parts but no impulse tests are required.

Realization of this directed greater effort toward the study of the problem of keeping lightning off transmission lines, or of reducing the overvoltage appearing at stations as the result of lightning. Some of the schemes used are relief gaps, shielding, low grounding resistances, and lightning arresters. However, in spite of improved protective devices, it became evident that apparatus, to insure satisfactory service, should have an impulse strength greater than had previously been considered necessary.

Also, it gradually became recognized that nothing would be gained by designing one piece of equipment on the circuit to have a higher insulation level than any other. This principle is known as "co-ordination of insulation" and led directly to the establishment of a set of basic insulation levels by a joint industry committee composed of representatives of the operators, the manufacturers, and the A.I.E.E.

TABLE II

STANDARD DIELECTRIC TESTS FOR CURRENT TRANSFORMERS

Insulation Class (Nameplate Rating)	Maximum Line-to-line Voltage	DIELECTRIC TESTS			
		Low Frequency	Impulse Tests		
			Chopped Wave		Full Wave
				Min. Time to Flash-over	
(Kv)	(Kv)	(Kv rms)	(Kv Crest)	(μ sec)	(Kv Crest)
(a)		(b)			
1.2	1.2	10	36	1.0	30
2.5	2.5	15	54	1.25	45
5.0	5.0	19	69	1.5	60
8.66	8.66	26	88	1.6	75
15 L	15	34	110	1.8	95
15 H	15	34	130	2.0	110
25	25	50	175	3.0	150
34.5	34.5	70	230	3.0	200
46	46	95	290	3.0	250
69	69	140	400	3.0	350
92	92	185	520	3.0	450
115	115	230	630	3.0	550
138	138	275	750	3.0	650
161	161	325	865	3.0	750
196	196	395	1035	3.0	900
230	230	460	1210	3.0	1050
287	287	575	1500	3.0	1300
345	345	690	1785	3.0	1550

(a) Intermediate voltage ratings are placed in the next higher insulation class unless otherwise specified.
(b) The secondary windings of instrument transformer shall withstand a low-frequency test of 2500 volts to ground and normally grounded core and other metal parts but no impulse tests are required.

Impulse test values for basic insulation levels were finally adopted after a great deal of investigation and are based largely upon operating experience and many laboratory and field-controlled tests. The latest test values for potential and current transformers are given in Tables I and II. These values are being included in the A.S.A. Standards for Transformers, C-57.

Not only is it necessary to standardize test values, but it is also necessary to establish a test code so that the impulse tests made in various laboratories may be comparable in their results. The following are extracts from the test code as it will appear in C-57:

INSULATION TESTS

2.035 STANDARD INSULATION TESTS—GENERAL

(c) Standard impulse tests consist of two applications of a chopped wave followed by one application of a full wave.
Either positive or negative waves may be used.

2.036 STANDARD IMPULSE TESTS

(a) Chopped-wave Test.
(1) For this test, the applied-voltage wave shall have a crest voltage and time to flash over in accordance with the table which appears in each section of these standards.

(b) Full-wave Test. For this test, the applied-voltage wave shall have a crest value in accordance with the table which appears in each section of these standards.

(c) Excitation During Impulse Test. During the impulse test (unless otherwise excepted in these rules) the transformer shall be excited at normal voltage and frequency and the impulse shall be timed within 30 electrical degrees of the crest of the normal frequency voltage of opposite polarity.

When the transformer group adopted the preliminary impulse test values, it became necessary to examine instrument transformer designs to see where they stood in reference to these new requirements, and it became apparent that the designs would have to be modified in a greater or lesser degree to make sure that the transformers would meet the new requirements of impulse testing. Initially, it was thought that it would not be economically feasible to require all transformers to meet the basic impulse insulation levels, particularly the small "dry-type" used on circuits in the voltage range 15,000 volts and below. Accordingly, a footnote* was added to the preliminary table of insulation tests stating that in certain voltages it would be permissible to utilize instrument transformers insulated to the "next lower insulation level."

However, the General Electric Company had for a long time designed and built instrument transformers with a high safety factor over the initial low-frequency test required by the A.I.E.E. rules. The value of this high factor of safety became quite evident when the new impulse test requirements were added to the previous low-frequency test, and some designs required very little, if any, change to make them meet the impulse test level requirement. In many cases the puncture strength of the insulation was

* A.S.A. Standards, C-57.3—4.056—Table 7. "(c) Indoor Instrument Transformers are available in the 2.5, 5, 8.66, and 15-kv classes insulated one level lower than the values in this tabulation."

already adequate for the impulse test, but increased flashover strength had to be obtained. In general, the designs are now adequate in reference to both puncture and flashover and meet the insulation levels required by the latest basic impulse insulation test requirements with no increase in mounting dimensions.

There are now available instrument transformers for all voltage circuits which conform to the requirements of the basic impulse insulation levels. The latest A.S.A. Standards no longer include the footnote regarding the use of the "next lower insulation level." Some of the new designs are actually smaller than the previous ones. This is illustrated in **Fig. 2**.

This improvement in the impulse strength of the insulation, particularly in dry-type transformers, has been accomplished by selecting materials better adapted for this purpose and by designs utilizing materials and methods to better advantage.

In G. Camilli's article "New Developments in Current Transformer Design," presented at the A.I.E.E. Scranton Meeting in October, 1939, several high-voltage designs were described using paper tape as the solid insulation. This paper has the property of readily becoming saturated with insulating liquids and forms a high-grade insulating material when vacuum oil-treated and even a better insulating material when it is vacuum-impregnated with asphaltic compound. This asphalt-treated paper tape is now used for dry-type instrument transformers up to the 15,000-volt rating.

Another advantage of saturating-paper tape is that, when creped, it will have as much as 100 per cent stretch and may be wrapped very closely around irregular shapes so as to fit any contour. When an instrument transformer has been insulated with this creped paper and properly treated with an asphaltic compound, the compound readily passes through the paper and flows to all parts of the transformer, forming a solid homogeneous mass of insulation in and around the windings, producing a design having a high insulation strength.

Still another advantage of saturating-crepe-paper is that it may be used in blanket or sheet form between sections of a winding and after this winding is completed, the protruding ends may be stretched up over the core and turned back like a cuff. When saturated with compound, this construction provides a very efficient barrier to prevent an arc forming over the sides of the winding during the cross coil test.

Additional improvements in insulation strength were obtained by careful analysis of the distribution of the electrostatic field throughout the structure of the instrument transformer. At those places where the dielectric stresses were concentrated, an effort was made to reduce them by modifiying the contour; and, if this was not sufficient, the insulation strength was increased at these points to obtain a balanced design. This analysis was so effective that in some cases a considerable increase in the over-all insulation strength was obtained, and at the same time the dimensions of the device were decreased.

To perfect a design and to obtain the desired impulse level with the minimum amount of insulating material, hundreds of impulse tests have been required. Only after the design has been put through cycles of extreme temperatures, from −40 C to +100 C,

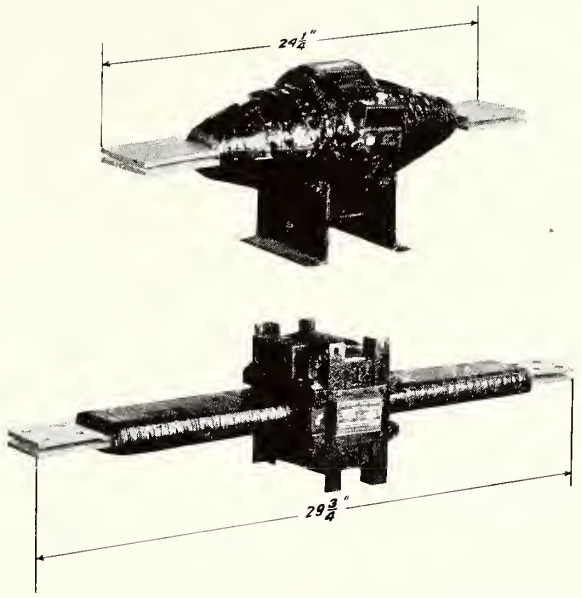

Fig. 2. Comparison of the new (*upper*) and previous (*lower*) designs of dry-type instrument transformers. The transformers shown are of 2000/5-amp rating. This advance in design resulted in increased surge strength and decreased size

and will still withstand the impulse test, is it considered ready for production. After the design is in production, periodic impulse tests are made to see that there is no let-down in quality of material or workmanship.

The need of applying an impulse test to every transformer has been carefully considered. However, a properly conducted impulse test is, and probably always will be, in the nature of a special test, requiring much longer time and relatively more effort than the low-frequency high-potential test. Moreover, experience has shown that it is possible to eliminate transformers which might fail on an impulse test by making a short 60-cycle test at a voltage considerably higher than the conventional minute low-frequency test. This procedure has been adopted by the General Electric Company as an effective assurance that every transformer, whether impulse tested or not, has adequate insulation strength to meet the impulse level for which it is rated.

INSTRUMENT TRANSFORMERS . . .

Greater insulation and impulse strength, better accuracy, and reduced size and weight in the new designs of liquid-filled instrument transformers

By I. H. SCLATER and G. CAMILLI
Power Transformer Engineering Department
General Electric Company

FOR years the design of liquid-filled instrument transformers followed that of power transformers. New developments in power transformers were quickly incorporated in instrument transformers; consequently their size, weight, and general appearance followed the conventional lines of power transformers. As one instance, when the General Electric Company introduced its shielded-winding design of power transformers, this feature was also included in instrument potential transformers.

However, as a result of constant research and development, the technique of porcelain manufacture improved to a point where it was economical to use the porcelain not only as a bushing, but also as part of the tank for current transformers. This important development was not applicable to power transformers but made possible the design of high-voltage instrument transformers which are a fraction of the size of previous designs. The comparison in Fig. 1 is of interest in this connection.

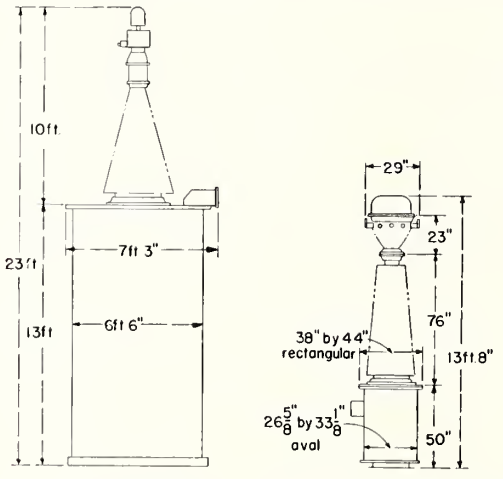

Fig. 1. Comparison of new (*right*) and previous designs in 230-kv current transformers

	Previous Design	*Modern Design*
Weight in pounds	40,000	4,200
Gallons of oil	3,200	115
Accuracy	1/4X, 1/4Y, 1/4Z	1/4X, 1/4Y, 1/4Z

A bank of single-phase metering outfits rated 230 kv is shown in Fig. 2. The present design would be but a fraction of the size of these units. Similar progress has been made in the design of high-voltage instrument potential transformers as illustrated in Fig. 3.

By careful utilization of basic laws of electrical breakdown of insulation[1] the design trends are getting closer and closer to the standards set up by the designers of oil-filled cables.

The modern high-voltage instrument transformer is the result of much original developmental work. Designers have not been content to follow the lead of the "big brother," the power transformer, but contribute their share to the over-all picture. Improvements in impulse and dielectric strength have been obtained without sacrificing accuracy. Hermetically sealing the units has reduced maintenance time and expense to a minimum. Reduction in size and weight have resulted in marked economy in floor space and general station layout.

Current Transformers

The progress made in the design of current transformers for medium and high voltage can be best explained in the light of progress made in insulations, including porcelain manufacture; also in the new developments made in the manufacture of a wound-core transformer under the trade name of Spirakore.*

In the high-voltage coil, provision can easily be made for the insulation between turns. Consequently, the coil may be considered as a single conductor which is insulated from ground. The analogy between this problem and that occurring in the design and manufacture of cables for medium and high voltages is apparent; indeed, in the development of the new type of insulation, advantage has

(1) "New Developments in Current Transformer Design," by G. Camilli, *AIEE Transactions*, pp. 835-42, 1940.
*Reg. U.S. Pat. Off.

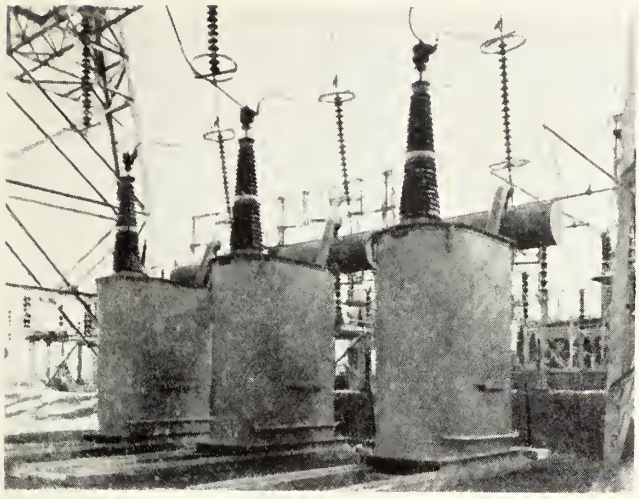

Fig. 2. Showing an installation of three 220-kv single-phase metering transformers of the former type of design

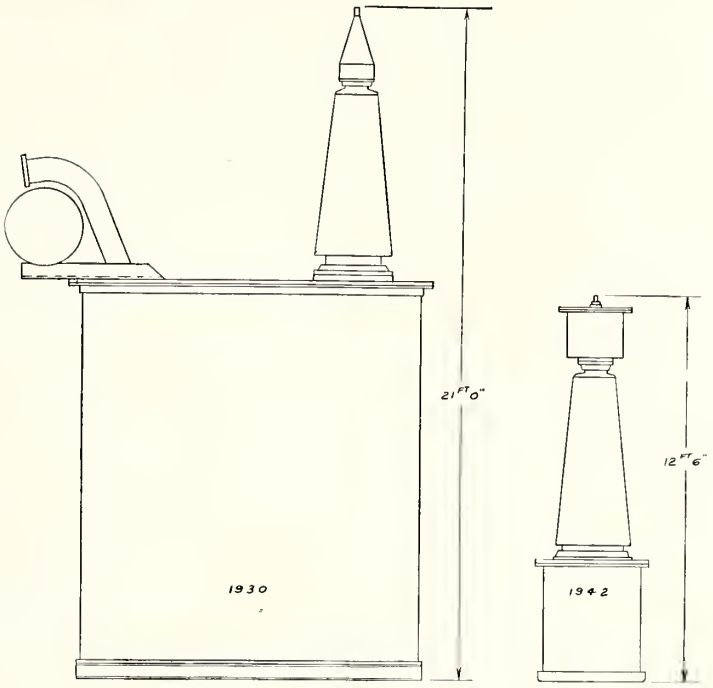

Fig. 3. Comparative outlines of the older (*left*) and new design of 230-kv potential transformers

been taken of the refined technique of high-voltage cable design.

Depending on the voltage rating of the transformer, the insulation of the high-voltage coil is either applied directly on the coil or on a metal shield which encloses the coil. In the lower voltage ratings, the turns comprising the coil are suitably spaced from each other and then the coil is insulated with paper.

In a typical current transformer, for use in very high-voltage circuits (115 kv and above), the high-voltage coil is enclosed in a split ring-shaped metal housing to which is attached a pipe enclosing the terminals of the coil. The coil, the enclosing ring, and the pipe are connected electrically and insulated by taping. The portion containing the high-voltage coil is covered with a metallic screen or shield which is connected to ground. This gives a construction known as the eye-bolt design.

The spacing between turns (in the case of medium-voltage transformers) and the spacing between the coil and the metal shield (in the case of the high-voltage transformers) provide channels for the free exchange of the liquid between the inside and the outside of the coil. These channels are very effective in the cooling of the apparatus as described later in this article under the heading *Thermal Characteristics*.

In medium-voltage current transformers (up to and including 69 kv) the complete high-voltage coil assembly is placed inside a porcelain shell, as indicated in **Fig.** 4; while in the higher voltage units (115 kv and above) the main body of the coil is placed inside a small steel tank, as shown in **Fig.** 5, with the lead-in extending upward through the porcelain shell.

The transformers are hermetically sealed, thus avoiding the danger of moisture entering into the

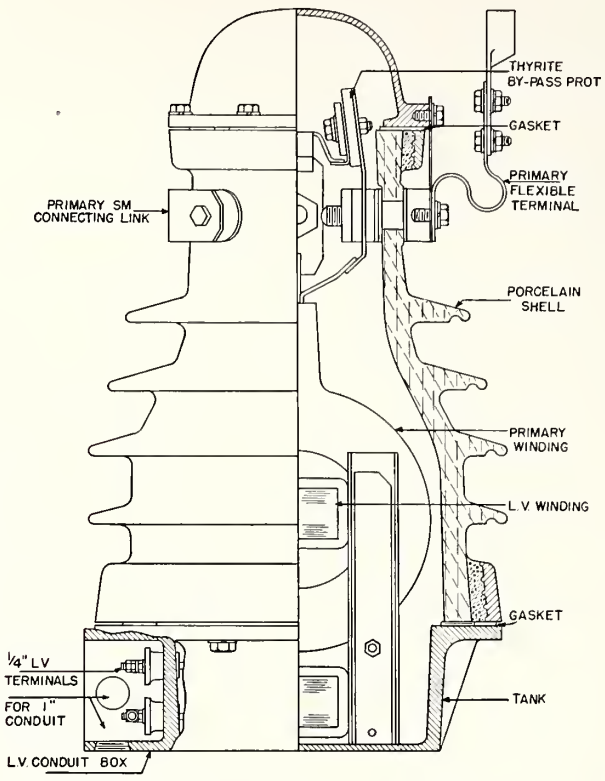

Fig. 4. A vertical semisection of a porcelain-clad current transformer for a 34.5-kv circuit

units. In addition, by carefully selecting the proper type of paper and by correctly utilizing a closely controlled heat-vacuum treatment, a very nearly flat power-factor-temperature curve is obtained; thus eliminating the danger of thermal instability. It also should be emphasized that in the new designs the solid insulation is fully utilized and under the most favorable conditions. The latter is the result of the elimination of oil ducts and the use of electrodes designed to give a uniform dielectric field.

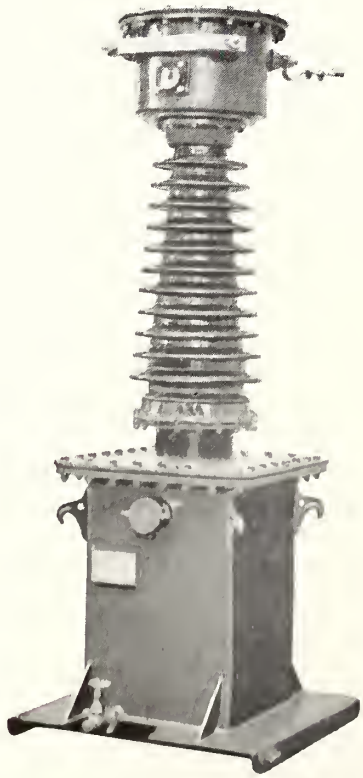

Fig. 5. Side view of a 115-kv eye-bolt type current transformer

Spirakore Wound-core Design as Applied to Current Transformers

Wound cores of strip steel have been in use for several years in distribution transformers with very satisfactory results. The main advantage of this Spirakore design lies in the fact that its excitation characteristics are much superior to those of the ordinary type of core which is built up of laminated punchings. Designers were quick to incorporate this revolutionary development in current transformers. The accuracy is greatly improved as the result of the more favorable excitation characteristics.

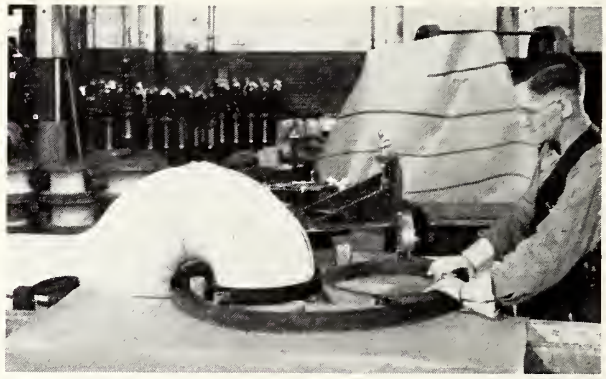

Fig. 6. Winding the core over the insulated high-voltage coil of a Spirakore current transformer

It is interesting to note that by the use of this type of core construction and special methods of compensation[1] it is possible to obtain high accuracy, both for metering and for relaying, without the use of cores made of nickel-iron alloys. In general, these alloys would be very desirable in the manufacture of current transformers if it were not for their high cost, their susceptibility to mechanical shocks, and their low saturation value.

Referring to **Figs. 6, 7** and **8**, the annealed core is wound over the insulated high-voltage coil, and then the turns of the low-voltage coil of the current transformer are evently distributed on the core.

Current transformers for the highest voltages have been designed with the characteristics of insulation and construction just described. Regarding the advantages of this combination it suffices to say that the secondary reactance of the current transformer is negligible, and as a result, the size and weight of the core are reduced to a minimum for a specified overload accuracy. A transformer for operation on a 230-kv system and incorporating the same general principles of the new type insulation and Spirakore construction is shown in **Fig. 9.**

Thermal Characteristics

Current transformers built along the lines indicated have excellent thermal characteristics under steady and transient conditions. It is interesting to note the flow of the liquid and the resultant cooling of these new high-voltage current transformers.

Referring to **Fig. 10**, under load conditions the oil inside the hollow ring B will be heated and will therefore rise to the expansion chamber A. In this chamber the oil will be cooled as a result of thermal radiation to the outside ambient and will return to the pipe and the hollow ring. There are two columns of oil flowing inside the connecting pipe C, one of hot oil flowing upward and the other of cold oil flowing downward.

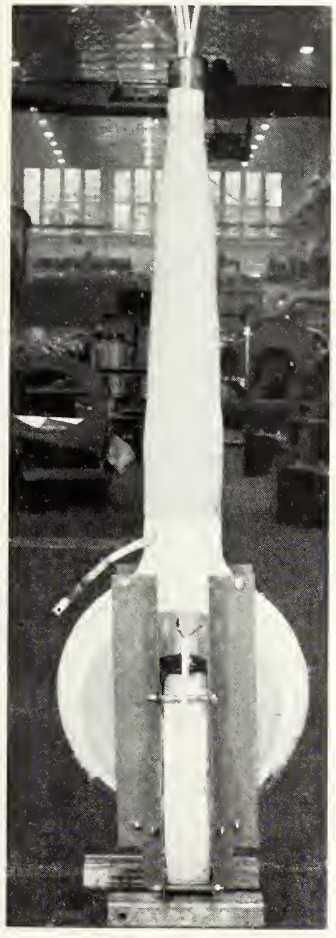

Fig. 7. View of core and coils of eye-bolt type current transformer for 115-kv circuit

Fig. 8. Showing the primary and secondary windings for a 34.5-kv Spirakore current transformer

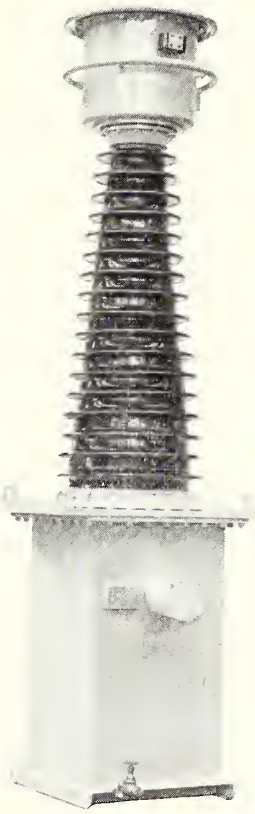

Fig. 9. External view of 230-kv eye-bolt current transformer

Another important design feature is that there is no dielectric stress in the oil circulating inside the metal tubing. Therefore, gas bubbles which might be generated in it under short-circuit condition cause no harm.

The above method of cooling does not, of course, apply to the lower voltage ratings. In this case most of the heat is dissipated by conduction through solid insulation, since its thickness is relatively small.

Plated Insulation

A novel insulating method has been developed wherein the high-voltage insulation is applied hydraulically. In this process kraft paper pulp highly diluted with water is applied directly to the high-voltage coils. The paper on the coil is deposited in layers like the ordinary plating of metals and hence the name of "plated insulation" has been given to this process.

Potential Transformers

Most of the advances in current-transformer design have also been applied to potential transformers. Developmental work in the latter field in recent years has consequently been directed primarily toward:

(a). Reduction of the size of the apparatus

(b). Improvement in the insulation and impulse strength.

Reduction of Size

In the new design the size of the high-voltage winding is greatly reduced and its insulation strength greatly increased.

In the conventional design the high-voltage winding is wound in small sections which are assembled together in the coil stack. The insulation between sections generally consists of an oil duct and a solid barrier. In power transformers these oil ducts had a useful duty to perform, that of cooling the windings. Fortunately, the copper loss in the high-voltage winding of a potential transformer is negligible, thus obviating the necessity for cooling, and therefore the complete insulating structure of the high-voltage winding can be modified.

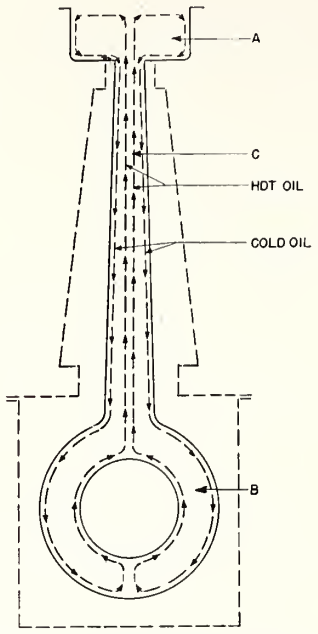

Fig. 10. Illustrating the oil circulation in an eye-bolt type current transformer

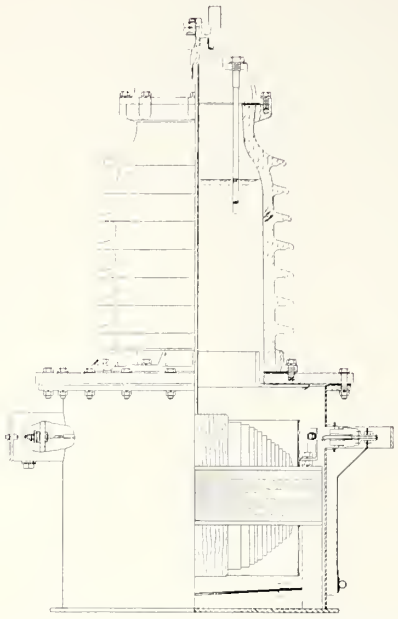

Fig. 11. Vertical semisection of porcelain-clad potential transformer for a 60-kv circuit

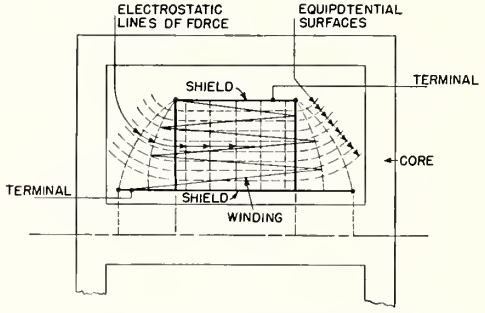

Fig. 12. Illustrating the high-voltage winding of the new potential transformers

It is recognized that the dimensions of a given insulating structure, consisting of an oil duct in series with solid insulation, may be greatly reduced by diminution of the free oil thereby utilizing the solid material most effectively.

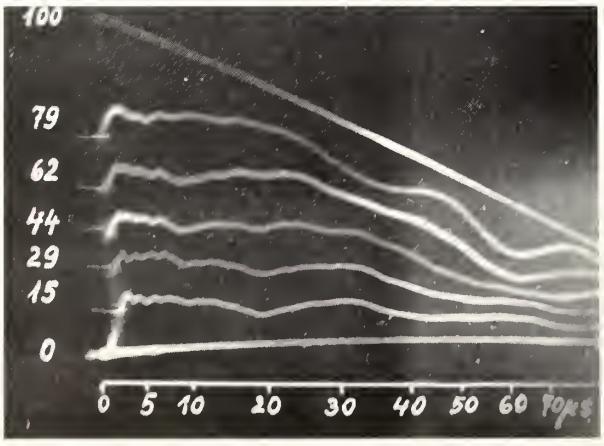

Fig. 13. Impulse-voltage distribution in the high-voltage windings of a 34.5 kv potential transformer when a 1½ x 40 wave is applied to various percentages of the high-voltage winding from ground

A careful analysis of the subject has shown that in designing potential transformers for use on grounded neutral systems the problem of insulating the high-voltage winding can be simplified by the use of the layer-wound type of construction.

As shown in **Fig. 11** the core and coils are assembled in a small tank and the lead-in extends through a porcelain shell similar to the shell of the current transformers. These new potential transformers also are hermetically sealed.

Layer Wound High-voltage Coil

In **Fig. 12**, the high-voltage coil is wound in continuous layers between several sheets of paper. Ducts are provided to facilitate the removal of moisture during the vacuum drying process. Dielectric losses are reduced to a very low value by careful heat-vacuum treatment and power-factor control.

The ground terminal of the high-voltage coil is connected to ground through a molded glass bushing to permit making insulation power-factor tests. The high-voltage coil is located between two metal shields (respectively connected to starting and line terminals) while the low-voltage coil is located between the high-voltage ground shield and the core. An important advantage of this design is that low leakage reactance is easily obtained, which is a controlling factor in the final accuracy of the transformer.

Impulse Strength

In this type of winding, uniform impulse-voltage distribution with nonresonating characteristics is obtained. In such a transformer the winding in question may be considered to be embedded within the dielectric of a condenser. Each turn of the winding is so located that, with uniform voltage distribution, its potential is the same as that which would exist in the dielectric at that point if the winding were not present.

In this way the electrostatic potential impressed on the turns is uniform and their insulation uniformly stressed. This has been proved by actual tests, as shown in **Fig. 13.**

This type of construction is used on transformers for operation on grounded neutral systems and for voltages up to 230 kv.

Conclusions

All of the foregoing improvements, reduction in size and weight, have been made without sacrificing the accuracy, dielectric or impulse strength of the transformers. On the contrary, the new designs have better accuracy and greater insulation and impulse strength than previous designs.

OSCILLOGRAPHY . . .

The magnetic oscillograph, its principles, and the readiness with which it can be utilized in measuring both electrical and nonelectrical quantities in modern industry

By J. E. HANCOCK
General Engineering Laboratory, General Electric Company

THE magnetic oscillograph is primarily a device for photographically recording the instantaneous values of one or more electrical quantities. For tests of complicated apparatus or investigations extending over relatively long times, the permanent records are invaluable. The instrument's ability to record several quantities simultaneously permits accurate analysis of the operation and performance of the device under test. The magnetic oscillograph (**Fig. 1**) is used, in preference to the simple indicating or direct-recording instruments, to study transient or quickly changing conditions.

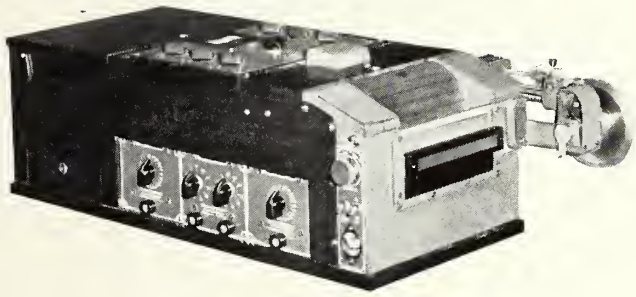

Fig. 1. The magnetic oscillograph

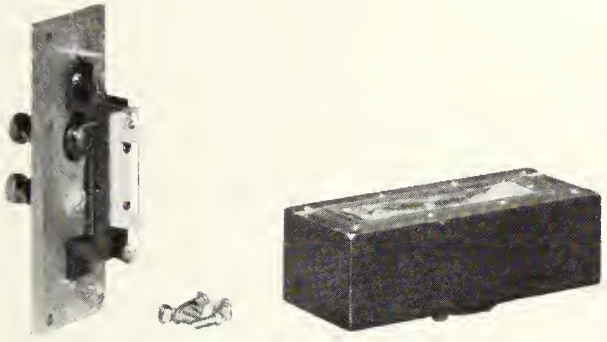

Fig. 2. Galvanometer for the magnetic oscillograph with the vibrator removed from the cell box

Galvanometers

The galvanometer (**Fig. 2**), which is the heart of the oscillograph, consists of two parts: the hairpin suspension with its small mirror, and the cell box or magnet which encloses the unit. The suspension is supported in the strong cross-wise field of the permanent magnet and is completely immersed in damping oil. Current in the strip acting with the magnetic field causes a twist or angular deflection of the mirror exactly following the instantaneous values of the current. Transverse movement of a light spot reflected from the galvanometer mirror records these values on the film.

A typical galvanometer responds faithfully to frequencies up to 2500 cycles per second and has a sensitivity (in the oscillograph) of 2.3 milliamperes per millimeter deflection on the film. Accompanying data (Table I and **Fig. 3**) show the accepted characteristics of other standard General Electric galvanometers. The values of frequency response and sensitivity plotted are averages obtained on production lots, and may vary ten per cent in individual units. The frequency plotted is that at which the galvanometer response is ten per cent below its d-c value, and the sensitivity is given in milliamperes per millimeter at

TABLE I

CHARACTERISTICS OF OSCILLOGRAPH GALVANOMETERS

Galvanometer	SENSITIVITY MA/MM		FREQUENCY CPS		Resistance Ohms
	As Used	At 1 meter	Resonance	Usable	
Cat. No. 5310680					
G1	2.3	1.25	4000	2500	0.9
G2	1.2	0.6	3000	1800	1.4
G5	7.5	4.0	9000	6500	0.9
G6	0.11	0.057	1500	700	9.0
Cat. No. 2645972					
G1	6.0	3.3	4000	2500	0.45
G3	3.0	1.6	2600	1500	1.0
G4	0.6	0.33	900	500	6.6
Cat. No. 3859770					
G1	5.0	2.7	5000	3200	0.8
G2	1.5	0.8	3000	1200	1.2
G6	0.15	0.08	1200	600	9.0
G11	8.8	4.7	8000	4500	0.8

All above values may be subject to plus or minus 10 per cent variation.

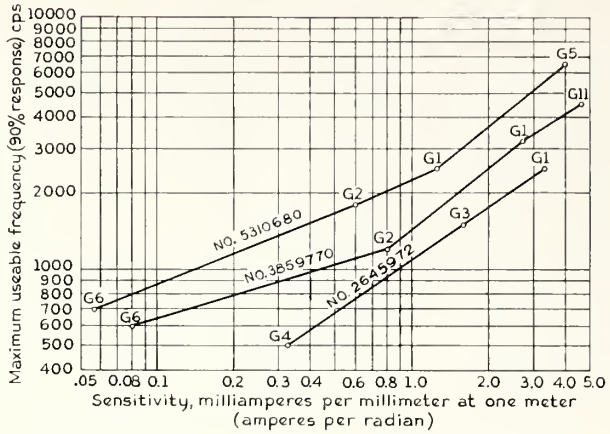

Fig. 3. Chart showing sensitivity and frequency response for various galvanometers

one meter beam length. Reducing the beam length to 21 inches (53.3 centimeters), as in one oscillograph (**Fig. 1**), increases these current values by a factor of 1.88.

The chart has been useful in comparing the merits of different galvanometers (the desirable qualities are to the top and left in **Fig. 3**); it also aids in deciding on the possibility of making a galvanometer having special characteristics, since possible modifications of existing units can shift the characteristics only along or below the plotted lines.

With appropriate shunts, the galvanometer elements may be used to record current, or with series resistors to record voltage. Current and potential transformers may also be used when recording large values of alternating current or voltage.

For recording instantaneous power (**Fig. 4**) in an electric circuit, two types of watt galvanometers can be used; one a single-element unit for recording single-phase or d-c power, the other a three-element unit for recording polyphase power.

Film Axis

Motion of the photographic film, driven by a constant-speed motor, produces the usual linear time axis on the record. On records of alternating currents and voltages of known frequency, no other timing wave is necessary. On other tests one galvanometer is usually used to give a record identifying the co-ordinate along the length of the film. For most tests a 60-cycle timing wave obtained from the power system is satisfactory; when no a-c supply is available an oscillator or vibrator pack may be used to supply the 60-cycle voltage for timing. Low-speed records require the use of a contact-making clock, either spring- or synchronous-motor driven, to obtain impulses at the rate of one per second, or one per minute, etc. If the length of the film does not represent time, some other identification will be used.

Zero Trace

Zero lines are usually desirable for each galvanometer trace. These may be drawn in with a pen after the film is developed, or they may be photographed in the drum-type holder by a double-exposure process. To photograph zeros and functions simultaneously, fixed-zero mirrors may be associated with each galvanometer to photograph a zero line, or small movable pins near the film plane may be set to split the galvanometer beam at its zero position and cast a shadow along the zero line.

Transient Tests

In the design of fuses, as well as in the design and production testing of many types of circuit breakers, it is often necessary to make oscillograms to study the interrupting characteristics of the device. In the simplest test, records are made of the current through the interrupting device and the voltage which appears across the break. The transient control switch is almost always used to close the circuit through an auxiliary circuit breaker in order that the current interruption shall occur during the time that the film is being exposed.

A somewhat similar condition sometimes investigated has to do with switching transients, as for instance the inrush current to a transformer bank or the starting current of an a-c motor. When the transient is of relatively long duration (**Fig. 5**), the records must be made in the continuous-drive type of film holder, and dependence placed on an accurate co-ordination by the oscillograph operator between starting the film and manually initiating the transient to be recorded. With a little practice an operator can usually control this timing within a quarter of a second.

Mechanical Performance Records

The oscillograph galvanometer like the d'Arsonval indicating instrument is essentially a current-sensitive device. With appropriate shunts it can be used to indicate larger values of current or with appropriate series resistors it can be made to indicate voltage. Like the indicating instrument, the galvanometer may also be associated with various intermediate equipment so that its indications are proportional to various nonelectrical functions.

Perhaps the most widely used auxiliary equipment is the strain-gage apparatus (**Fig. 6**) which converts

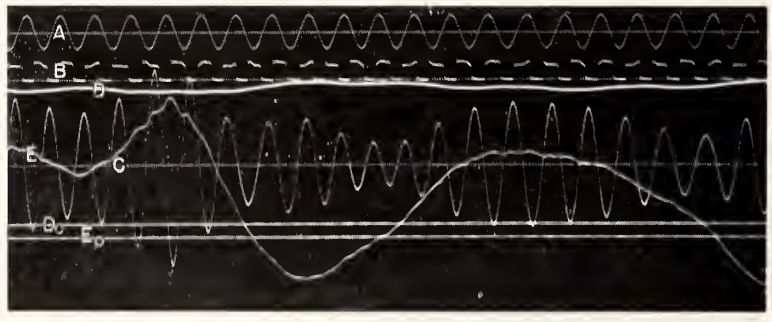

Fig. 4. Test on textile loom motors

(A). Sixty cycle timing
(B). Crankshaft angle (10 degrees per span)
(C). Line current
(D). Motor speed
(E). Motor 3-phase power

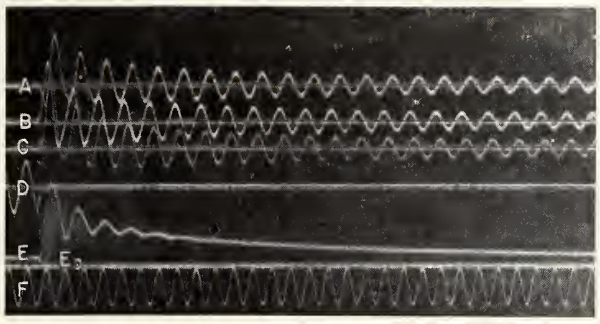

Fig. 5. Single-phase short-circuit test on a-c generator

(A). Current in phase 1
(B). Current in phase 2
(C). Current in phase 3
(D). Line voltage
(E). Field current
(F). Sixty-cycle timing

usual magnetic strain gage for many of these tests, use is being made of the small wire or resistance-strip strain gages which may be cemented directly to a surface being investigated without materially affecting the air-flow.

In some tests of turbine governor performance, it has been necessary to record not only the shaft speed and electrical output but also to utilize strain-gage equipment to record the motion of the governor and control parts. In this sort of test on multivalve turbines it is sometimes desired to record the time of opening and closing of the several valves. To accomplish this purpose, limit switches may be mounted so

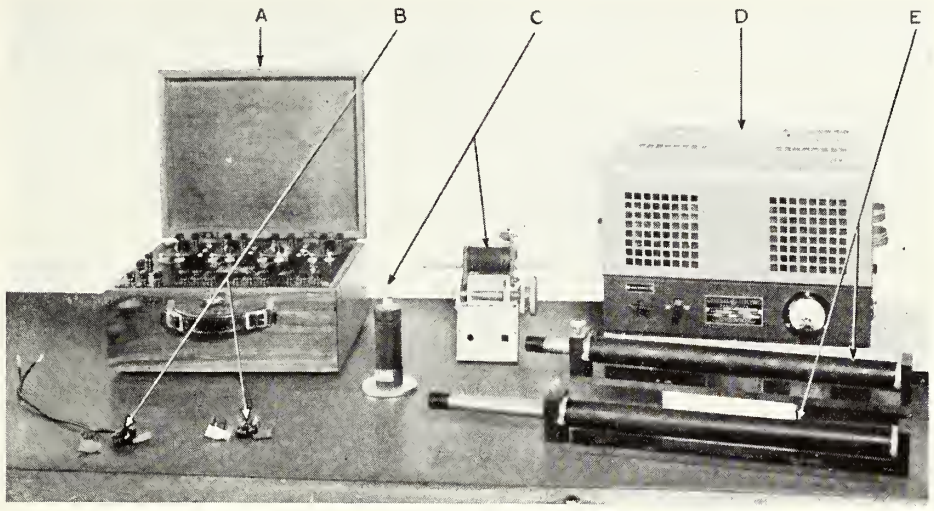

Fig. 6. Strain-gage and travel-recorder equipment

(A). Strain-gage power unit
(B). Strain gages
(C). One-inch travel recorder and balancing unit
(D). Oscillator and power supply
(E). Sixteen-inch travel recorders

mechanical motion into electric current. With the oscillograph this equipment is used to record quick variations in many mechanical systems. Fundamentally the detector unit converts mechanical motion into an impedance variation which, in turn, produces a varying unbalance in an impedance bridge. The rectified and filtered unbalance current, applied to the oscillograph, produces a record which is interpreted in terms of the original motion.

Strain-gage Measurements

The magnetic strain gages have been applied to recording the motion and dynamic loading in members of a railroad bridge. In one application the data obtained prevented scrapping of the bridge as otherwise indicated by empirical calculations. Another application of similar equipment was made in measuring the loads and movements of various parts of a large locomotive. Other measurements recently undertaken have had to do with the relative and absolute motions of parts of a structure when subjected to shock and impact loading.

A large field of application is at present being built up in the aircraft industry, measuring and recording the motions and stresses occuring in various parts of an airplane under flight conditions. Instead of the

as to be operated by the several valves. A network of resistors may be made up and connected to a steady d-c voltage and the limit switches arranged to change the total circuit resistance in steps. An oscillographic record of the current through the resistor network will then have steps occurring as each successive valve opens or closes.

Motion of Small Parts

In many investigations it becomes necessary to record the motion of extremely small mechanical parts. Because of size or loading limitations, it may not be possible to apply strain-gage detectors or any of the other motion-recording devices. In these applications it is often possible to utilize the moving part itself in obtaining a record of its motion by introducing it into the optical path of the oscillograph. In one method the part, with a small mirror attached to it, is mounted at or near the galvanometer position in the oscillograph. Rotary motion of the part through small angles will twist the mirror and move a light spot on the film. In another scheme, the galvanometer may be replaced by a fixed mirror and the moving mechanical part introduced in the light beam in such a way as to cast a shadow on the film. With proper adjustments, either of these methods will give an oscillographic

record of the motion of small mechanical parts without loading them in any way. The mechanisms may also be mounted outside the oscillograph and studied by these methods if other mirrors and lenses are arranged to focus the light beam on the film.

In research problems involving the study of electric arcs and arcing phenomena it was possible to provide a special optical system to photograph the arc stream on the film simultaneously with the recording of the electrical characteristics. This required the addition of extra lenses and mirrors in the oscillograph and the accurate location of the arc in order that its image be focused on the film plane. The record was somewhat similar to a sound-on-film moving-picture film.

Sound and Vibration

In many classes of apparatus, design problems arise involving measurement and analysis of sound or vibration. The vibration meter or the sound-level meter will give amplitude indications, and frequency analyzers are available to measure the various frequency components, but it is only by means of oscillographic recording that a complete picture of a vibration or noise can be obtained. An amplifier is required with any detector unit or microphone to obtain sufficient power for operating the oscillograph galvanometer. It is quite important that the detector and amplifier have sufficiently broad characteristics to accurately record the vibration encountered. The records obtained (of either sound or vibration) will show not only the relative amplitude under different conditions, but also will clearly indicate the phase angles of the components present. In one such test, a large number of oscillograms was taken of the vibration of a steam-turbine shaft. Study of the records led to the source of the vibration and permitted a solution of several related governor difficulties.

Rotational Speed

Speed may be easily recorded using any one of several tachometer generators to convert the speed being measured into a voltage. A direct-current tachometer generator is usually preferable since its generated voltage changes polarity with a change in direction of rotation. For those tests involving a wide range of speed (**Fig. 7**), the tachometer generator is usually connected to a potential galvanometer to simply record the voltage generated, which is then interpreted as speed.

In other tests, as for instance investigation of governor characteristics, the speed range to be measured is quite small, making it difficult to obtain sufficient sensitivity for satisfactory recording. For these tests, a special circuit may be set up in which a steady d-c voltage, equal to the tachometer-generator voltage at nominal speed, is introduced in the circuit; with this bucking circuit the effective voltage is only that due to speed variations. Commutator ripple from the tachometer generator may be eliminated by a simple low-pass filter which is easily connected in the circuit. With this bucking and filter circuit, accurate measurements of speed variations in the order of two or three per cent can easily be recorded.

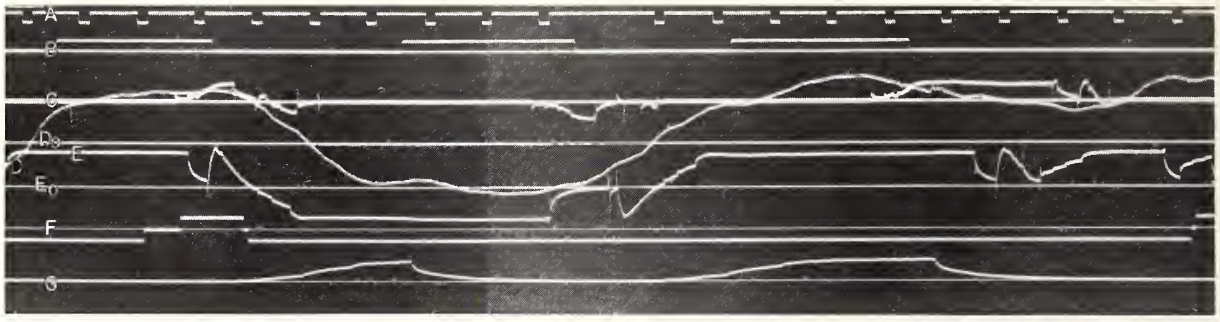

Fig. 7. Tests on 44-inch blooming mill drive motors

(A). One-second time intervals
(B). Pass indications
(C). Screw-down motor armature volts
(D). Roll speed
(E). Table motor armature volts
(F). Manipulator indications
(G). Table No. 1 motor armature volts

Tests without Time Axis

In all of the tests previously described the film is run through the oscillograph at a uniform velocity. The records so obtained show the relative time of occurrence of various events, since measurements along the length of the film correspond to time. The use of the oscillograph, however, is not limited simply to this type of measurement since motion of the film may often be linked to some element other than time.

The film may be made to move in proportion to the motion or rotation of some part of a machine being tested by a direct gear connection or Selsyn equipment. This will make the film-holder drum, and thus the linear positions along the film, correspond to the angular position of some part of the device under test.

The film in the drum-type holder may also be moved to correspond to the magnitude of some current or voltage being observed. An amplidyne motor may be used to turn both the film holder and a rheostat mounted on the same shaft. The rheostat would tap off a portion of its constant total voltage to balance against the observed voltage, and the difference supply the amplidyne control field.

In one proposed use of this apparatus the film

holder is driven by an amplidyne motor in proportion to the voltage generated by a tachometer generator. Thus the co-ordinates along the lengths of the film correspond to the speed of the motor being tested. Strain gages mounted on the motor give a response proportional to the torque of the motor. A film made with this setup would then be a direct speed-torque curve on the motor and would give information impossible to obtain by measurement of several steady-state conditions.

A somewhat similar arrangement might be made whereby the rotation of the oscillograph film holder would turn a rheostat to obtain a controlled voltage to apply to the device being tested. With this arrangement, the co-ordinates along the length of the film would be the applied voltage. A setup of this kind might be used for recording the characteristic curves of vacuum tubes where the controlled voltage is applied to the grid of the tube and the plate current recorded through the galvanometer.

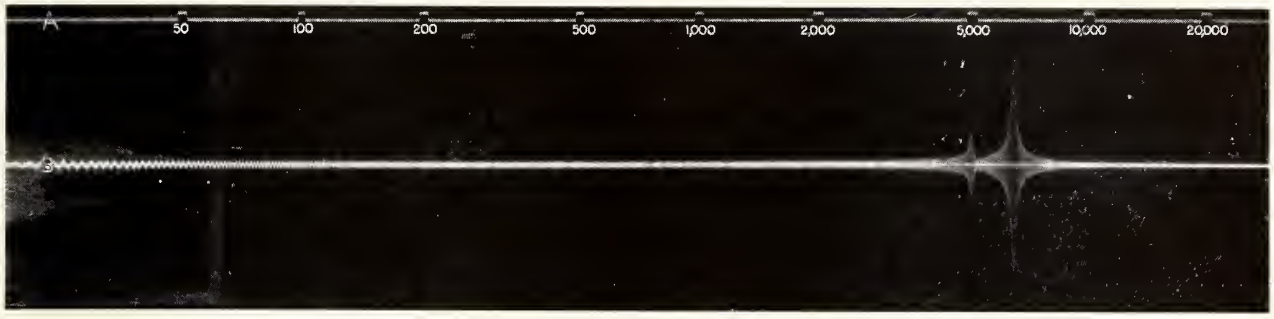

Fig. 8a. Frequency-response (undamped) tests on galvanometers
(A). Frequency scale (B), Response of 3859770G1 galvanometer

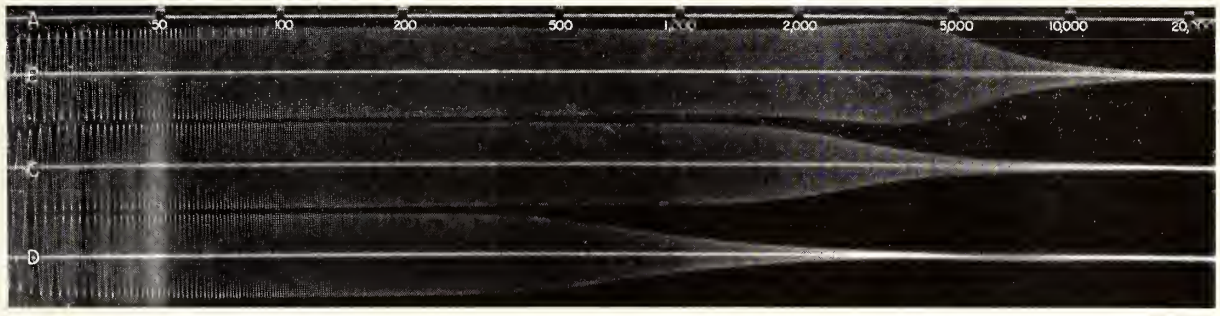

Fig. 8b. Frequency response (damped) tests on galvanometers
(A). Frequency scale
(B). Response of 3859770G1 galvanometer
(C). Response of 3859770G2 galvanometer
(D). Response of 3859770G6 galvanometer

Another useful method for recording without the time axis is to make the rotation of the film-holder driving pulley control some function of the test setup. This seheme has recently been used in a large number of tests of frequency-response characteristics (**Figs. 8a** and **8b**). For this test the oscillograph film drive also is arranged to drive the frequency-control dial of an oscillator, thus the co-ordinates along the length of film are made to correspond with the frequency applied to the device under test. Contact pins set in the frequency dial of the oscillator are used to obtain marks along the film at known frequencies.

Conclusion

The magnetic oscillograph may be used in the investigation, design, or testing of many machines and devices. The permanent records show the simultaneous variations of the instantaneous values of a number of quantities. The galvanomter itself is a current-sensitive electrical unit; however, its deflection may be made proportional to many nonelectrical functions by intermediate apparatus. The co-ordinates along the length of the film usually correspond to time, although, for special tests, other axes may be chosen by an appropriate setup.

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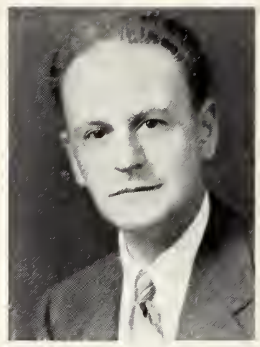
ELECTRIC GAGES . . .

Some will read to a millionth of an inch. Convenient to use and reliable, these gages serve in an almost limitless variety of applications



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THE electric gage briefly described here is fundamentally an a-c bridge circuit in which one or more impedance branches are acted upon by the quantity to be measured. The calibrated amount of bridge unbalance is indicated on an instrument which may be remotely installed at any convenient location.

With some exceptions, reactance-type gage elements serve as the active bridge members. Whenever their application is possible, gage elements of this type are preferred over elements of other types because of their relatively low inherent impedance, large useful range, good stability, and immunity to electrostatic and magnetic interference effects.

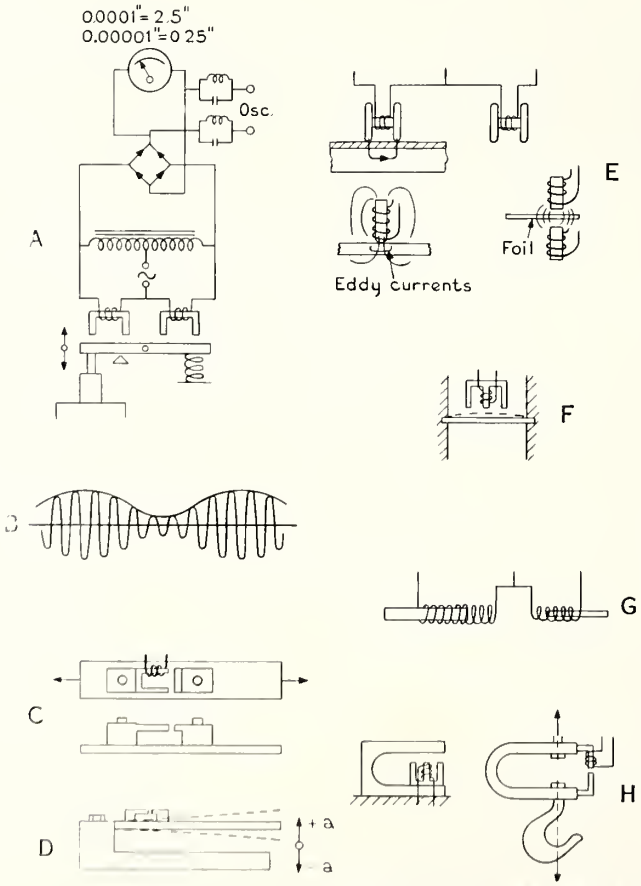

Fig. 1. Schematic representations of electric-gage circuit applications

A; one of a variety of electric-gage bridge circuits. *B*; a representation of the fundamental frequency employed and its modulation by variations in the quantity being measured. *A* and *C* to *H*; representations of several different applications of the electric gage; *A*, comparator; *C*, strain; *D*, acceleration; *E*, thickness; *F*, pressure; *G*, displacement; *H*, weight

In its simplest form an active electromagnetic impedance element consists, for example, of a U-shaped iron yoke and an iron armature placed near the open ends of the U, leaving small air gaps. A coil is placed on the iron yoke and is connected in the a-c bridge circuit. It is evident that when the air gap between the iron yoke and the armature decreases, the reactance of the coil increases. In this case, the bridge output is a function of the armature displacement and may therefore be calibrated in terms of this displacement.

An arrangement of this type may be made exceedingly sensitive, depending on the initial air-gap setting. Assuming, for example, that the initial air-gap setting is 0.002 in., closing the gap by 0.001 in. will produce approximately a 100 per cent reactance change and a correspondingly large bridge circuit output. While the sensitivity may be increased much further by simply reducing the initial air gap, practical limits are reached because of temperature expansions of the gage members and of the parts to be gaged. In general, reliable readings of one hundred-thousandth inch are obtainable; and under carefully controlled conditions armature displacements as small as one millionth inch may be read.

In the foregoing example a reactance change was obtained by varying the air gap in a magnetic circuit. As far as the bridge circuit is concerned, it is immaterial how the coil reactance or impedance change comes about. For example, an impedance change may also be obtained by placing in the air gap, which is made large in this case, a sheet of conducting material. Because of the alternating flux traversing this sheet, eddy currents are set up in it which affect the coil impedance. This effect depends on the resisitivity of the sheet material as well as on its thickness. It is seen, however, that with a material of given resistivity, the bridge circuit can be calibrated in terms of sheet thickness.

In **Fig. 1** are shown schematically some representative applications of the electromagnetic gage principle. In this illustration is shown how the principle is applied to comparator, thickness (air-gap and eddy-current types), displacement, pressure, strain, acceleration, and weight gages. It is seen that the electromagnetic gage principle is extremely

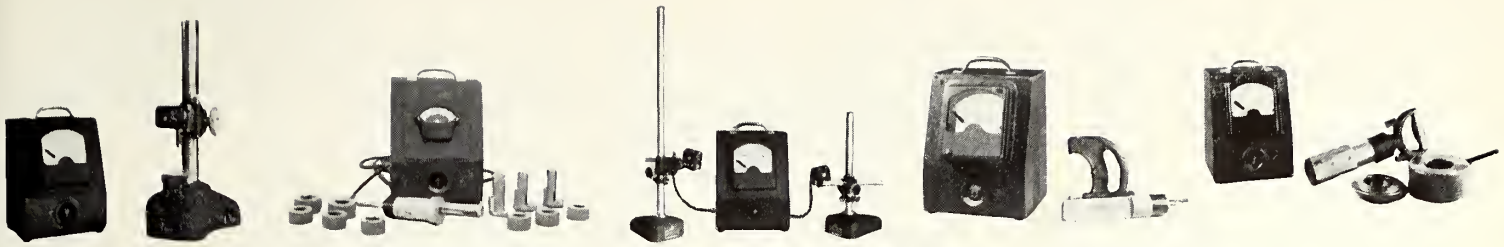

Fig. 2. Electrolimit gages of the Pratt & Whitney Division of the Niles-Bement-Pond Company, showing (*left to right*) external comparator, internal comparator, height gage, snap gage, and cylinder-bore gage

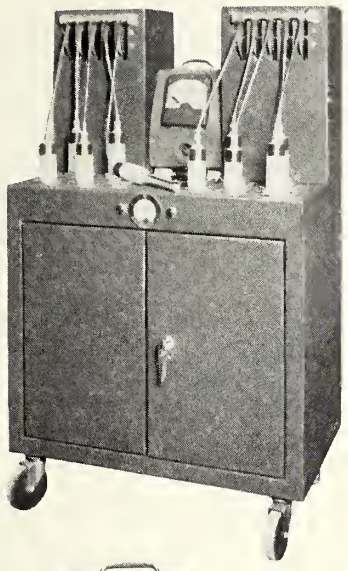

Fig. 3. Electrolimit internal hand-gage cabinet. This equipment is used for accurate production checking of lapped holes

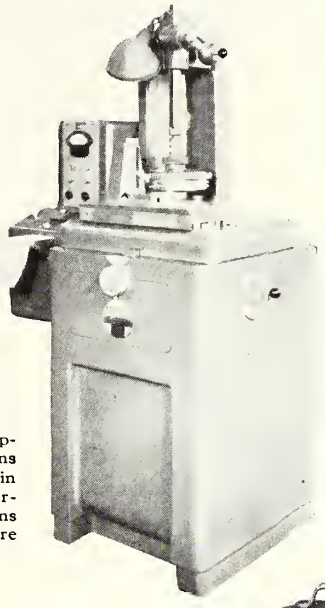

Fig. 4. Electric gage equipment for recording deviations from standard profiles, used in Fellows Gear Shaper gear-testing machines. Deviations as small as 0.00005 in. are recorded

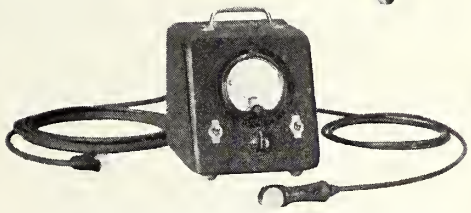

Fig. 5A. Thickness gage for paints, lacquers, and electroplatings on steel. This gage is also used to measure the thickness of silver, bronze, and babbitt linings on steel-bearing shells

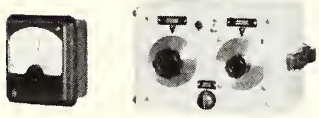

Fig. 5B. Thickness gage for nonconducting sheets, such as Lucite. Thickness measurements are made by placing the sheet on a steel table. This gage covers a range from $\frac{1}{32}$ in. to $\frac{3}{4}$ in.

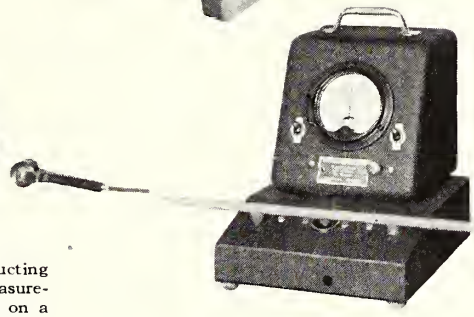

Fig. 5C. Gage for checking the eccentricity of flux coatings on iron welding electrodes

Fig. 5D. Magnetic gage for measuring the thickness of steel sheets. This gage has two ranges; one from 10 to 25 mils and the other from 20 to 45 mils

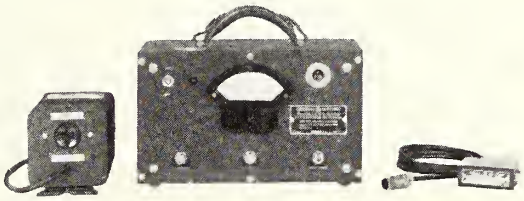

Fig. 5E. Eddy-current-type gage for measuring, from one side, the thickness of conducting but nonmagnetic sheets, plates, wall thickness of castings, pipes, and tanks. Aluminum plates have been measured to a thickness of one inch. This gage is used for the inspection of aluminum and magnesium castings for aircraft engines

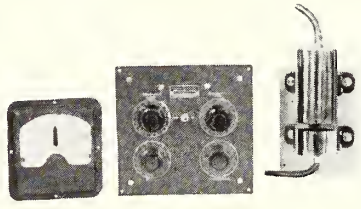

Fig. 5F. Eddy-current-type metal-foil thickness gage. This gage is used in aluminum rolling mills for indicating and controlling the thickness of aluminum foil

Fig. 6A. Diaphragm-type pressure gage for use up to 1000 lb per sq in.; various stages of assembly and complete unit

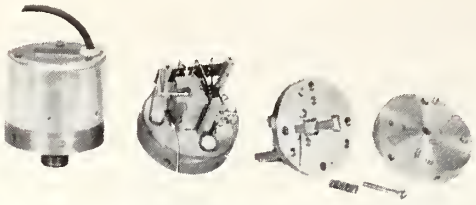

Fig. 6B. Piston-type pressure gage for use up to 15,000 lb per sq in.; complete unit and various stages of assembly. The gages in Figs. 6A and B operate from a 2000-cycle supply and without an amplifier are capable of driving an oscillograph galvanometer. They may be calibrated with static pressures, and they have a frequency response up to 500 cycles per second. The auxiliary equipment, such as 2000-cycle oscillator and the bridge circuit unit, is shown in Fig. 10

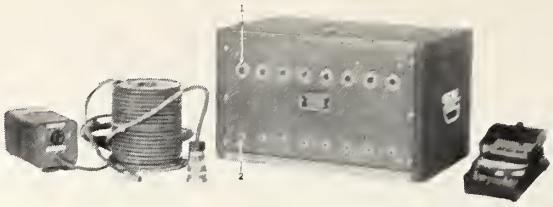

Fig. 6C. Self-contained 8-channel amplifier pressure-gage equipment for 8 lb per sq in. The pressure-gage heads are designed for flush mounting in the wall of the pressure chamber. These gages are used in a marine testing basin for the study of wave pressures. With the most sensitive attenuator setting, full-scale deflections are obtained with 1 lb per sq in. pressure. The maximum-frequency response of these gages is 100 cycles per second

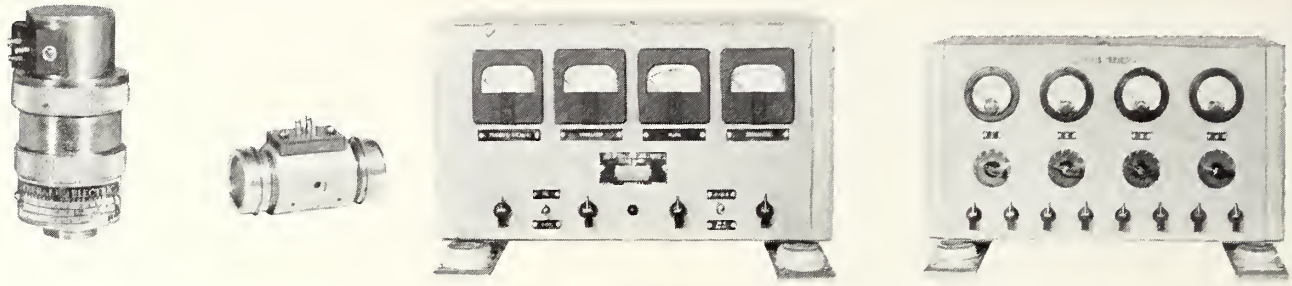

Fig. 6D. Pressure-gage equipment for the study of aircraft engine performance. The small gage (approximately 1¼ in. diam. and 2½ in. long) is designed to respond to air-pressure pulsations of a few inches of water column. The larger gage is for use on the intake manifold and is designed for air pressures from 0 to 25 lb per sq in. absolute. The fuel pressure gage rated at 20 lb per sq in. (not shown) has exactly the same appearance as the manifold-pressure gage. The power unit operates either from a 12-volt storage battery or from the 115-volt 60-cycle supply. It includes a regulated 2000-cycle oscillator for the excitation of the gages and a regulated B-power supply for the amplifiers. The amplifier unit has four identical stabilized channels with tapped attenuators

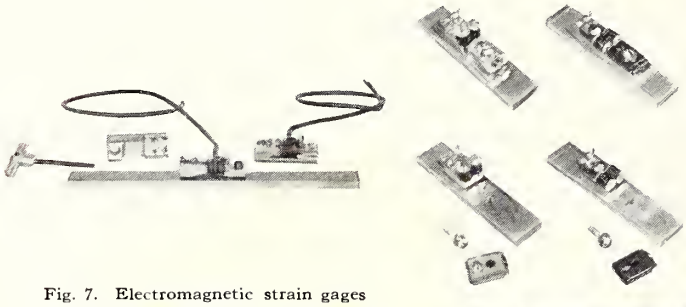

Fig. 7. Electromagnetic strain gages

(*Left*) Strain gage with 2¼-in. gage length. This gage, without an amplifier, is capable of driving an oscillograph galvanometer. It operates with the auxiliary equipment shown in Fig. 10

(*Right*) Strain gage with one-inch gage length. This gage was designed for aircraft use and weighs 0.5 oz. Two types are available; one for use on steel, and the other for use on aluminum. They require amplifiers for operating the oscillograph galvanometers

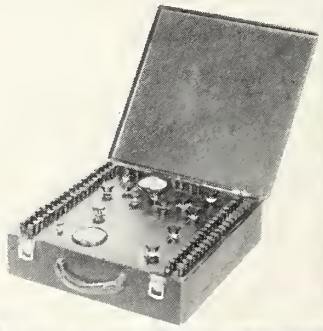

Fig. 8. Portable strain-gage bridge that accommodates 40 of the 2¼-in. electromagnetic strain gages shown in Fig. 7. This equipment is used to measure static stresses in steel structures. Sixty cycles is used for the excitation of the bridge circuit

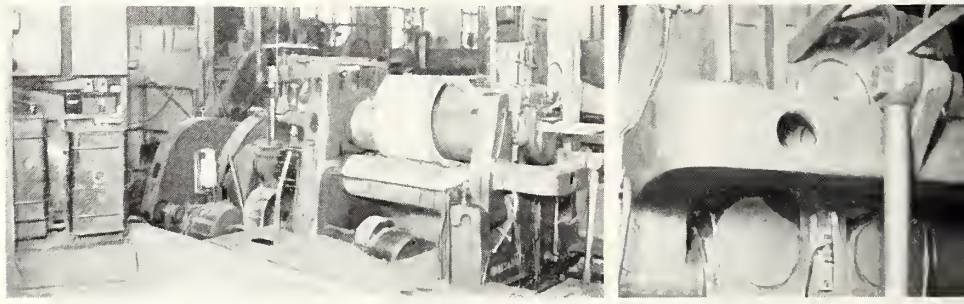

Fig. 9. Strain-gage equipment in use for indicating overloads on a pyramid-type bending roll. This gage equipment may also be applied to other machine tools, such as shears and punch presses, for the protection of these machines

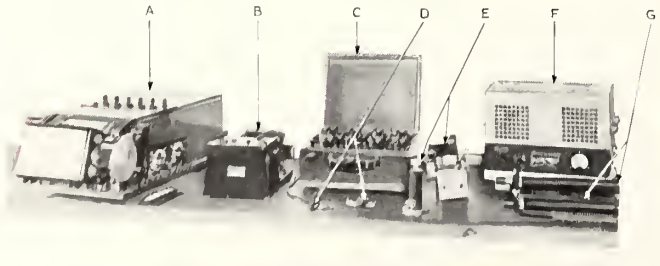

Fig. 10. Oscillograph strain gage and travel recorder equipment

A: Oscillograph
B: Film drive motor
C: Four channel power unit containing gage bridge circuits, rectifiers, and output filters
D: 2¼ in. electromagnetic strain gages
E: One inch travel recorder
F: 50-watt 2000 cycle oscillator and power unit
G: 16-in. travel recorders. The travel recorders are used to record large linear motions up to 16 in.

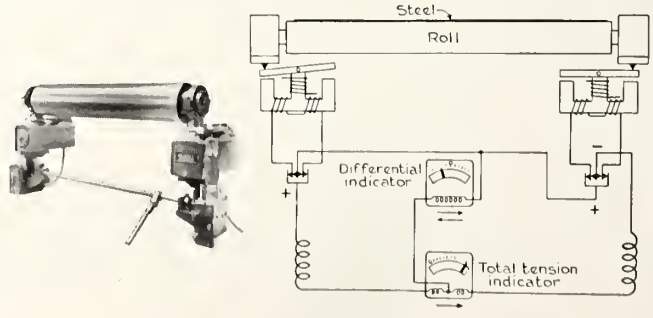

Fig. 11. Tensiometer equipment. The sheet to be rolled runs over the tension-indicating roll, deflecting its cantilever supports. The schematic circuit diagram shows the electric-gage circuit connections and performance

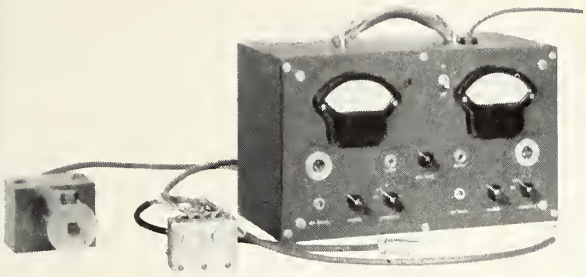

Fig. 12. Tool-pressure gage equipment indicating simultaneously and independently vertical and horizontal forces acting on the cutting tool (not responsive to thrust). This gage is used in the study of machineability of materials, cutting angles of tools, and effects of coolants. It was designed for use on a lathe but may also be used on a shaper

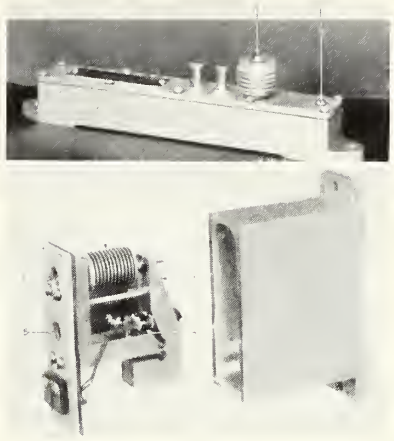

Fig. 13. Accelerometer (*top*), and air-speed indicator. In these devices, developed for aircraft use, the deformation of elastic members is measured with one-inch electromagnetic strain gages, shown in Fig. 7

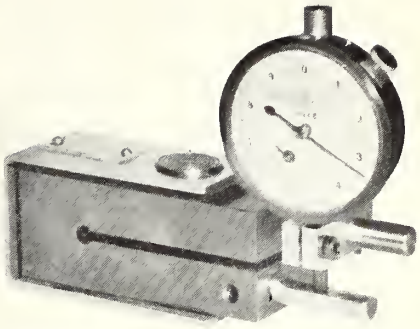

Fig. 14. Electrode pressure gage. This is a mechanical gage that was developed for checking the pressure between welding electrodes. In this and other suitable applications it will indicate forces applied to the pressure pads up to 4500 lb, each dial division representing 10 lb

versatile and numerous other possible applications will suggest themselves. The electric gage will measure any mechanical quantity which can be translated into a relative displacement between two parts.

As already mentioned, alternating voltage is used for the bridge excitation. Therefore, the bridge output voltage is alternating also and has the same fundamental frequency as that which is applied. Although a-c instruments may be used to indicate the bridge-circuit output, d-c instruments are generally used. The latter type inherently has a very much greater sensitivity and in addition has a linear scale which is desirable. When d-c instruments are used suitable rectifiers are connected into the bridge output circuit as shown in **Fig. 1A**.

When the quantity to be gaged varies, the alternating output voltage from the bridge circuit also varies accordingly. The fundamental bridge frequency, however, is retained except that it is modulated corresponding to the frequency of the variations. Slow variations can be followed by an indicating instrument, but more rapid variations require the use of a fast-responding recorder or an oscillograph. In order to reproduce the variations faithfully, there must be available a sufficient number of loops of the fundamental frequency for their reproduction. In general, it may be said that the frequency applied to the bridge circuit should be at least four times as high as the frequency of the variations which are to be recorded. Thus, with a bridge excitation of 60 cycles per second, good reproductions may be obtained of variations up to 15 cycles; and with a bridge excitation of 2000 cycles, variations up to 500 cycles may be recorded.

When records are taken with a magnetic oscillograph of the unrectified bridge output, the fundamental frequency is recorded modulated by the frequency of the variations. By connecting into the galvanometer circuits suitable rectifiers and filters, the fundamental carrier frequency may be suppressed, leaving only the trace of the variations. This procedure gives a single-line record which is highly desirable and it also permits using high sensitivity oscillograph galvanometers in that they do not have to follow the high fundamental frequency.

This article is confined to electromagnetic types of gages. Their fundamental principle has been reviewed, and it was pointed out that this principle is preferred whenever it can be applied to advantage. Other types of gage elements are also in use. Among them may be mentioned the capacitance type, in which the capacitance between two electrodes is changed by moving these electrodes with respect to each other. Because of the very small capacitance of the active element, stability is attainable with difficulty.

In another type, particularly for the measurement of strain, resistance elements are often used. These elements are cemented on the test members and the resistance of these elements changes slightly (a fraction of one per cent) under strain.

Some photoelectric gages are also in use in which small variations in a light beam brought about by small mechanical displacements are converted into electrical equivalents. Where the desired frequency response is very high piezo-crystals are often used. Successful experiments were also made using the well-known magnetostrictive principle. In this application use is made of an element having suitable magnetic properties which change the permeability of the element when it is stressed.

The photographs in this article show some of the most important gage types in use today. They perform a variety of unique gaging functions and represent, in many cases, the practical solutions to gaging problems.

TIMERS AND TIME METERS . . .

The importance of timers and of time meters for the efficient utilization of plant machinery and for the control of manufacturing processes

By C. H. RIDGLEY and J. L. THEISEN
Time Switch Engineering Department
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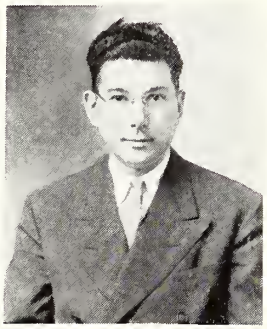


C. H. Ridgley

THE art of measurement arises from a sense of curiosity. The observer wants to know how much there is of whatever he is observing. This "curiosity of quantity" exists in some persons—the research scientist, for example—as an end in itself. In others, it is a means to an end.

In industry there is a desire to know "how much," but not just for the satisfaction of knowing; after we know, we usually want to do something about it. Put into more formal terms, the attainment of a measurement is the prelude to an act of control. After our breakfast egg has boiled for three (or four) minutes, we want to remove the source of heat. So it is with industry, which can use the time switch both to measure and to control.

J. L. Theisen

The War of Production in which we are now engaged has developed a recognition of the importance of Time far beyond the general concept in periods of peace. Out of this experience may come lasting lessons of economies which will contribute to the maintenance of our accustomed level of living.

Time is no longer simply "the measurable aspect of duration" as indicated by the hands of a clock. Time is now a *tool*. The extent to which this is recognized will determine the sequence of events which finally lead us to the permanent peace toward which we work. Those of us who have the responsibility for industrial production and design should recognize these facts and make immediate use of every available means of attaining maximum results.

Fig. 1. General purpose time switch

Industrial Uses

Flood lights	Conveyors
Factory lights	Automatic elevator "parking"
Electric furnaces	Solder pots, glue pots

Time-study engineers have made great progress in recent years toward more efficient scheduling of manual operations. More production in a shorter time with less effort has resulted. Machine designers have been ingenious in increasing the speed of machines and in replacing human effort and judgment by automatic means. These studies, however, must go much farther. As long as skilled labor is interrupted by periods of inactivity or for the performance of unskilled operations; and as long as the outcome of critical processes is dependent upon the judgment of operators for sequence and duration of events, we have not gone far enough. Such conditions are not necessary. We should assist our men and our machines with refinements which offer still more output with less effort. The means are available. Let's put time to *work*.

Let us visit some typical industrial plants. First we see a tool department with highly skilled men and good machines. A die maker is idle—waiting to use a grinder. It seems that someone is always waiting to use this grinder. The waits aren't long—maybe twenty or thirty minutes—but neither are the jobs. During a week, a good many lost hours are quietly accumulated.

TABLE I

PERFORMANCE OF INDUSTRIAL TIMERS AND RELAYS

Characteristics	Timers			Relays		
General	Telechron motor-timed interval-type (nonrepeat). Adjustable	Telechron motor-timed repeating ON and OFF. Fixed time cycle	Capacitor-discharge-timed interval-type (nonrepeat). Adjustable	Telechron motor-timed interval-type (nonrepeat). Adjustable	Magnetic flux-decay interval-type. Instantaneous pickup —time-delay drop-out	Magnetic flux-decay interval-type. Instantaneous pickup —time-delay drop-out
Power supply	25, 50, or 60 cycle a-c	25, 50, or 60 cycle a-c	25 or 50/60 cycle a-c*	25, 50, or 60 cycle a-c*	D-c (Also a-c with rectifier)	D-c (Also a-c with rectifier)
Maximum voltage	230	230	230	600	600	600
Range: Forms available provide timing						
From—	0–5 seconds	10 seconds (total cycle)	0.045 seconds	4 seconds	0.25 seconds	2 seconds
To—	0–6 hours	1 hour (total cycle)	120 seconds	2 hours	2 seconds	**7 seconds
Adjustment range on each form (per cent maximum time)	0–100%	†1–99%	5–100%	Approx. 10–100%	Approx. 50–100%	Approx. 50–100%
Repeating operation (Close contact, reset, and start new interval automatically)	With one timer (requires additional contact at zero—optional)	Repeats ON and OFF time continuously	Requires two timers—time independently adjustable	Requires two timers—time independently adjustable	Requires two timers—time independently adjustable	Requires two timers—time independently adjustable
Time to reset	1 second	Continuous operation	Varies from 0.116 sec to 1 sec in different forms	Instantaneous	Instantaneous	Instantaneous
Contact rating 115 v	1 amp	10 amp	1 amp(‡10 amp)	15 amp	5 amp d-c continuous	5 amp d-c continuous
Contact rating 230 v	1 amp	10 amp	0.5amp(‡5amp)	15 amp		
Circuit arrangement	SP—ST	ST—DT	SP—DT	SP—DT	Up to 4 circuits	Up to 4 circuits
Method of setting timing	Optional—either external or internal setting and can be locked	Internal	External	Internal	Spring-tension adjustment	Spring-tension adjustment
"Stepless" adjustment	Yes	Yes	Yes	Steps approx 5% max time	Yes	Yes
Scale marking	Time units	Per cent	Per cent	Time units	None	None
Possible timing error due to voltage fluctuation	None	None	Voltage drop increases time slightly and vice versa	None	None	None
Visual indication of elapsed time	Yes	No	No	No	No	No
Mounting	Surface	Conduit	Surface	Surface or panel	Mounted, or unmounted, or in NEMA Type I case	Mounted, or unmounted, or in NEMA Type I case
Enclosure	§NEMA Type I case	§NEMA Type I case	§NEMA Type I case			
Dimensions	9 in. high 6⅛ in. wide 4 in. deep	5 in. diameter 3⅛ in. deep	7 1/16 in. high 4⅞ in. wide 4½ in. deep	5 in. high 6½ in. wide 6 in. deep	—	—
Wiring connection	Terminal board	Leads	Terminal board	‖Terminals	Depends on type	Depends on type

* Available also for operation on direct current.
** Additional time delay can be obtained by special modification.
† ON time adjustable from 1 to 50% of total cycle. ON time from 50 to 99% obtained by simple change of connections. Per cent time OFF is the difference between ON time and total cycle.
‡ Special form.
§ Also available without enclosure for mounting.
‖ Panel type has back-connected studs that go through panel.

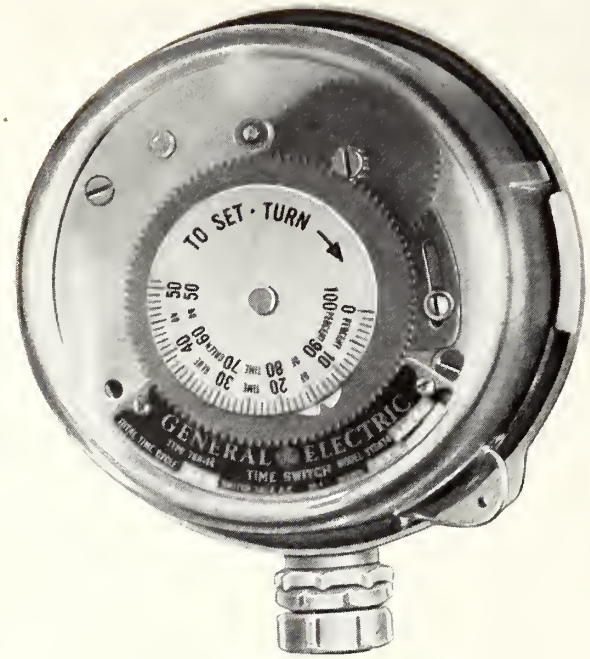


Fig. 2. Short-time repetitive-cycle switch

Industrial Uses	*Typical Operation*
Mixing vats	On 20 min; off 10 min
Washing tubs	On 2 min; off 2 min
Conveyors	On 5 sec; off 15 sec
Exhaust fans	On 5 min; off 25 min
Pumps	On 10 min; off 20 min
Filter cleaning	On 1 min; off 59 min

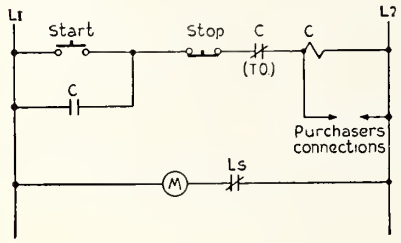
In the same shop, the superintendent asks the foreman if he can release one of his shapers for another important job. The shaper isn't being used at the moment but the foreman knows that at times all of his machines are in use. So, he reports that he can't get along without the shaper.

Definite knowledge of machine utilization would help that shop. It would show that the grinder is a "bottleneck," and better scheduling or additional capacity has been necessary for some time. It might also show that the available shapers are not being economically utilized and that one of them can be spared without affecting production.

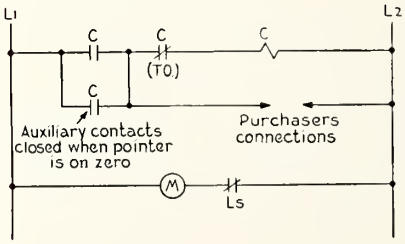
All of this information could have been supplied by periodic time-meter records for each machine. Because this information is not available, skilled labor is being wasted and production delayed until a new shaper arrives. Similar conditions can be found in the screw machine, punch press, and heavy machine departments.

Now let us visit some of the processing rooms. A furnace is used as an important part of a process. Material is put in the furnace and is to be held at a prescribed temperature for a definite time to obtain a uniform product. The *temperature* is closely controlled by automatic means, but the *time* depends upon the operator's watching a clock, shutting off the heat after one period, and removing the material after another. Nonuniformity of treatment results from the variations in time of heating and cooling.

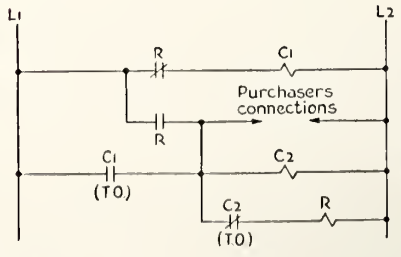
Industrial Uses	*Typical Time Cycles*
Electric furnaces	2 hours
Molding presses	30 sec
Baking ovens	30 min
Centrifuges	5 min
Pumps	10 min
Dryers	15 min



Time switch with clutch-coil contact for adjustable time interval and automatic reset.



Time switch with clutch-coil contact and auxiliary contact for adjustable time interval; automatic reset and repeat.



Two time switches and a relay connected for adjustable automatic control of "open" and "closed" time of a circuit. (Timing motors not shown; connected L_1 to L_2.)

Fig. 3. Automatic reset interval timer and typical connection diagrams

This nonuniformity causes rejections when the final test of the product is made with consequent loss of labor and material.

In the mixing room, vats are filled and emptied by manual operation of valves. Agitation periods are controlled by the operator, who watches a clock. In the assembly room, a conveyor is started and stopped manually to allow operations to be performed at various stations. The periods are nonuniform because they are regulated to the operator requiring the longest time. Thus, some operators have periods of inactivity.

The foregoing examples illustrate common practices which, throughout industry, use human effort and judgment in place of simple, reliable, automatic means. Uniformity of product can be improved and cost can be reduced by judicious application of proper time switches.

In these ways, timed, automatic control can help the various departments of a factory produce more goods in a shorter interval.

When applying time switches to industrial uses, there are three general classes of switches to be considered:

(1). *General Purpose*—24-hr repetitive-cycle switches with plain or astronomical dial. Adjustable daily schedules may be set up, with provision to omit operations on chosen days. Astronomical dial is convenient for timing dusk and dawn operations, and is usually used when lighting is to be controlled.

(2). *Short-time repetitive-cycle switches*—continuously repeating a series of on-off operations for one or two circuits. Fixed time cycles, available over wide range, with proportion of "on" time to "off" time adjustable.

Fig. 4. Types of time meters: (*left to right*) panel-mounting, two designs: conduit mounting; portable
Industrial Uses: Punch presses, conveyors, molding machines, screw machines, welders, drill presses, electronic equipment

An automatic-reset interval timer or a combination of two timers would control the heating time of the furnace after loading and sound an alarm when the material is ready to be removed. Each load would then receive exactly the same treatment and the operator could perform other duties without having to watch a clock.

The mixing vats could be made entirely automatic by combinations of automatic-reset interval timers and repetitive time switches. The operation of filling and emptying valves, and the length of agitation periods, could be timed within close limits. The process would become more uniform, and the operator would be released for interim duties.

A repetitive-cycle time switch would control the operation of the assembly conveyor so that the periods of movement and rest would be uniform. The time-study engineer could then rebalance the operations so that all operators would complete their work in the same period and with comparable effort.

(3). *Automatic-reset interval timers*—nonrepeating to open or close a circuit at an adjustable time after starting. Can be made continuously repeating by adding optional contacts. Wide range of time cycles.

Each of these time switches will perform many duties, and in combination can be made to do practically any kind of control job which can be set up as a function of time. Table I shows detail characteristics of some of the common timing devices.

The automatic machine is one of the evidences of advancing civilization. The time switch which controls the machine is a more subtle indication of the increasing complexity of these advances. As man progresses, he tries to do in as easy a way as possible the things which must be done. The automatic time switch, by putting time to work as a tool, is another example of the way in which man sets himself free to consider new problems, to scale new heights of accomplishment, to win a war, to make the world a better place to live in.

MAGNETIC MATERIALS . . .

How the application of modern magnetic alloys has improved the design and the performance of a-c and d-c electrical indicating instruments

By A. J. CORSON
Instrument Engineering Department
General Electric Company

RECENT practice in the design of electrical indicating instruments has been greatly influenced by developments in magnetic materials,[1] particularly the nickel-iron alloys such as permalloy,[2] mumetal, and nicaloi for a-c applications, and the aluminum-nickel-iron alloys for d-c applications. The use of these materials has led to very interesting results, both in terms of improved instrument performance and in kinds of instruments that have become available. The following article is a brief summary of typical developments, and a similarly brief description of the new magnetic properties on which these developments are based. These applications will be classified according to the nature of the material and instrument; namely, the use of nickel-iron alloys in a-c instruments, and of aluminum, nickel-iron alloys in d-c instruments.

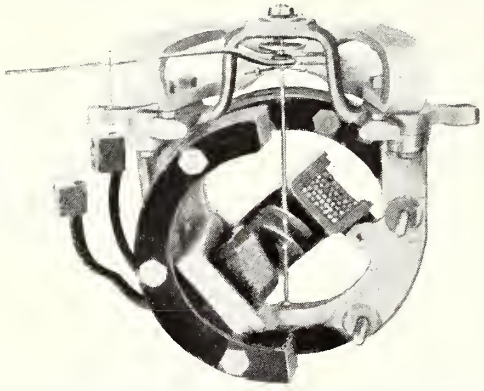


Fig. 1. Typical construction (cut-away) of an inclined-coil moving-iron-vane a-c instrument. The gain in accuracy of this instrument through the substitution of permalloy for silicon steel is shown in Fig. 2

Application of Nickel-iron Alloys to A-c Instruments

The characteristics of three nickel-iron alloys—nicaloi, permalloy, and mumetal—in comparison to a good grade silicon steel are given in Table I. The nickel-iron alloys are characterized by extremely low hysteresis losses and extremely high initial permeability. The reduction in hysteresis losses improves the performance of moving-iron instruments which are designed for general-purpose applications involving use of the instrument on both alternating current of distorted wave form and on d-c circuits. A typical construction, the Thomson inclined-coil mechanism for voltmeters and ammeters, is illustrated in **Fig. 1**. The gain in accuracy due to the direct substitution of permalloy for silicon steel in the moving element is shown in **Fig. 2**. It is even greater than one would expect by comparison of the hysteresis values of the two materials. In this particular instance, the gain has been of sufficient magnitude to place the instrument in the same accuracy classification as those of the electrodynamic type, bearing in mind that the shielded electrodynamic element will also show small errors due to the shielding.

The second application of the new low-loss nickel-iron alloys to electrical indicating instruments is illustrated in **Fig. 3**, the mechanism of an a-c wattmeter

(1) "Recent Developments in Magnetic Materials," by C. E. Webb, *Journal of I.E.E.*, vol. 82, p. 303, March 1938.
(2) "Permalloy, an Alloy of Remarkable Magnetic Properties," by Arnold and Elman, *Journal Franklin Institute*, vol 195, p. 621, May 1923.

TABLE I
CHARACTERISTICS OF MAGNETIC MATERIALS FOR A-C INSTRUMENTS

Material	Approximate Composition	Initial Permeability	Losses in watts/lb at 60 cycles at 50 kilolines/sq inch			Res. in Microhms Per cm³
			Hysteresis	Eddy Current	Total	
0.014″ Silicon Steel	3% Si	500	0.40	0.10	0.50	56
0.014″ Nicaloi	50% Ni	5000–9000	0.07	0.11	0.18	45
0.014″ Permalloy	78% Ni	5000–14,000	0.06	0.18	0.24	17–20
0.020″ Mumetal	75% Ni 4% Cu 1.4% Cr	10,000–30,000	0.03	0.20	0.23	46

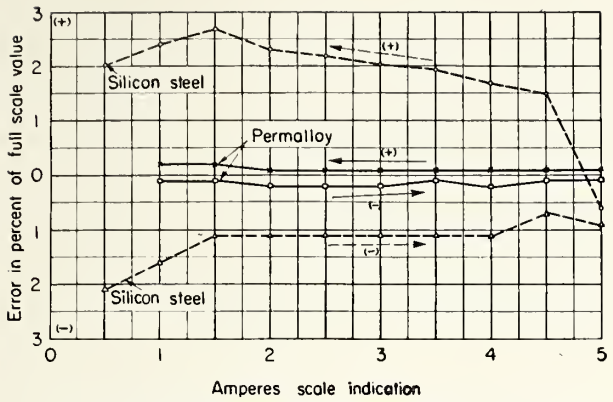


Fig. 2. Comparative performance of instruments having either permalloy or silicon-steel moving vanes. Hysteresis effect shown for descending and ascending scale readings. Given in terms of 60-cycle calibration

for switchboard use. This mechanism consists of a nicaloi core electromagnet, having an air gap of sufficient angular length to permit a usable scale of 240 angular degrees. The losses although quite small are still of sufficient magnitude as to require compensation for low power factor errors. This compensation can however be readily accomplished; and when combined with careful design of the electromagnets, there results an instrument of about twice the conventional scale length and one which fully meets accepted standards of performance for this class of service.

Application of Aluminum-nickel-iron Alloys to D-c Instruments

In considering the influence of the high coercive magnetic materials on d-c instrument design, attention is directed to **Fig. 4**, showing the characteristics of these materials. Here, we are interested in the direct opposite of the previously described quality; that is, in a very high instead of a very low coercive force, combined with a suitable value of residual induction, for a maximum available energy.

If we take as a base line the chrome and tungsten steels, it is found that they are characterized by coercive forces in the order of 60 or 70 oersteds, a residual induction of about 9000 gausses, and a maximum external energy value of about 0.3×10^6. Considering as typical of the newer materials, Alnico II, we obtain corresponding values of 520 and 540 oersteds for coercive force, 6900 and 7200 gausses for the residual induction, and 1.4×10^6 and 1.6×10^6 for maximum external energy for the sintered and cast materials, respectively. This remarkable

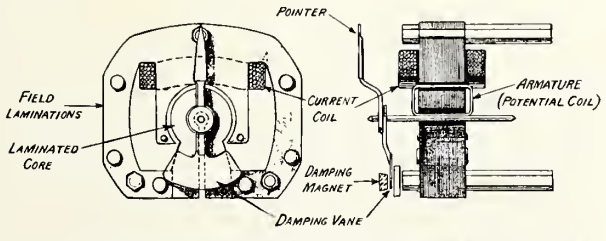


Fig. 3. Mechanism of 240-angular-degree switchboard type of a-c wattmeter, the design of which is made possible by the use of nicaloi for the core

gain in available external energy per unit volume and in coercive force has had a marked effect on the geometry of permanent-magnet moving-coil instrument mechanisms.

With the former materials, the limitations in these values necessitated long U-shaped magnet sections, or even magnets in the form of a horseshoe. With the latter materials, instrument engineers have developed elements in the concentric shape which characterizes a motor or a generator and hence such instruments have been called "concentric-magnet instruments." One such instrument, a d-c voltmeter, is illustrated in **Fig. 5**. The air-gap flux density of the concentric-magnet instrument is about 66 per cent greater than that of the former design, specifically about 2500 gausses instead of 1500 gausses. This flux density represents a corresponding increase in available instrument torque per unit of energy input to the moving system. Hence this development in magnet

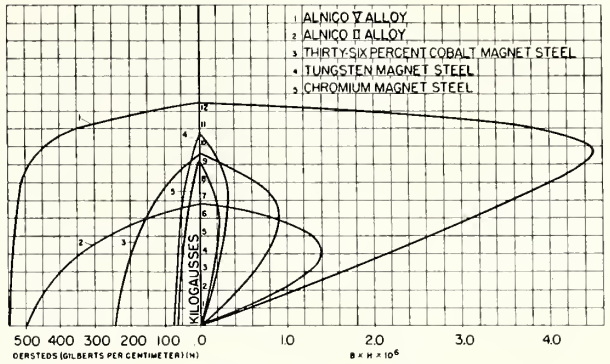


Fig. 4. The advantages of the new permanent-magnet materials over the older are shown by these approximate demagnetization and available-energy curves of the materials

steels has resulted in much greater reliability and sensitivity of the instruments. The new magnet systems are self-shielded, and the magnets are highly resistant to demagnetization. Therefore the instruments are particularly immune to external demagnetizing influences.

The instrument element just referred to is one of the conventional 90-deg angular scale type. Another, and possibly more significant advance in instrument design, has resulted from the application of the aluminum-nickel alloys to instruments of the long-scale type.

Such an application is illustrated in **Fig. 6**, which shows the mechanism of a d-c ammeter. The similarity in general outline to the a-c wattmeter element using nicaloi as an electromagnet material is evident. The alnico permanent magnet for the d-c instrument replaces the nicaloi core electromagnet for the a-c instrument, and d-c ammeters and voltmeters are thus produced. Again, an angular air gap of sufficient length for a usable scale arc of 240 angular degrees is obtained, with an increase of 2 to 1 in the scale length of the instrument.

All of these materials, together with the newer special-purpose permanent-magnet alloys, such as

sintered oxide and silver alloys, are subject to an exacting technique both in manufacture and in application which this brief discussion does not cover. One point however is to be noted. The direct substitution of a new material for an older material may lead to unsatisfactory results, the obvious point being that the geometry of the magnetic circuit must be suited to the demagnetizing curve of the material involved. The manufacturing[3] and design[4] technique has been described in various publications and the procedure is more or less straightforward, with the possible exception of the computation of leakage fluxes. If we

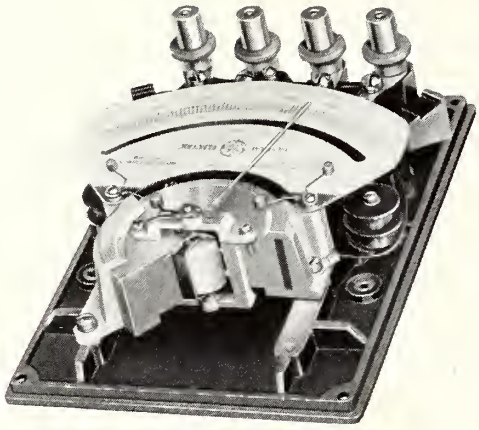


Fig. 5. Aluminum-nickel-iron alloy is used in this concentric-magnet d-c voltmeter, in which a section of the magnet assembly is cut away to show the construction

define the efficiency of the magnetic design by the ratio of the air-gap flux to the total magnet flux at its maximum point, we will find an efficiency of roughly 30 per cent for the older U-shaped design and about 50 per cent for the more compact concentric magnet design. It is, therefore, to be expected that still higher efficiencies will be obtained upon the advent of materials having higher coercive forces.

Conclusion

Summarizing, we find that the range of magnetic values occupied by the silicon, chrome, and tungsten steels has been expanded in two directions. Coercive forces, hysteresis losses and attendant total losses have been minimized by the advent of the nickel-iron alloys, resulting in vastly improved performance of a-c instruments and the availability of a-c instruments of new kinds. Similarly, the advent of extremely high loss aluminum-nickel-iron alloys (from which very powerful permanent magnets are obtained) has led to improved performance of d-c instruments and the availability of instruments of the new type. Among the developments which owe their origin directly to improved magnetic materials, may be listed:

(a). The improved Thomson inclined-coil movement for a-c voltmeters and ammeters

(b). The concentric-magnet d'Arsonval instrument[5]

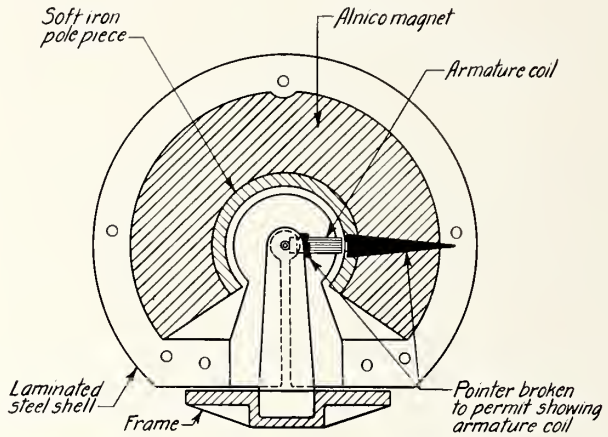


Fig. 6. Diagram of a d-c ammeter which has a 240-angular-degree scale and a permanent magnet of alnico

(c). A complete line of long-scale switchboard indicating instruments, having a scale length of 6.8 in. in a 4¼-in. rectangular case[6]

(d). Miniature moving-magnet instruments[7] with sintered oxide rotors, and silver-aluminum-manganese control magnets.

These, and other developments, involving the use of modern magnetic materials, have been a very considerable part of the instrument engineer's contribution to the war effort. Progress, particularly in the field of permanent-magnet materials, is actively continuing. We may therefore expect similar progress in the applications of these materials, with resultant improvement in the devices to which they are applied.

(3) "Permanent Magnets," by J. H. Goss, *Metals and Alloys*, vol. 15' p. 576, April 1942.

(4) "The Output and Optimum Design of Permanent Magnets Subject to Demagnetizing Forces," by A. J. Hornfeck and R. S. Edgar, *AIEE Transactions*, vol. 59, p. 1017, 1940.

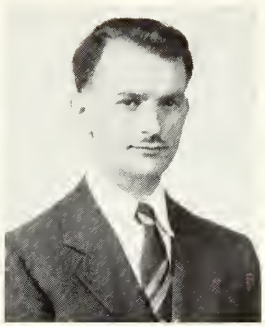
(5) "A New Measuring Instrument for Direct Current," by H. T. Faus and A. J. Corson, *AIEE Transactions*, vol. 59, p. 683, 1940.

(6) "The Design of Long Scale Indicating Instruments," by A. J. Corson, R. M. Rowell, and S. C. Hoare, *Electrical Engineering*, vol. 61, p. 318, June 1942.

(7) "A New Moving Magnet Instrument for Direct Current," by H. T. Faus and J. R. Macintyre, *AIEE Technical Paper, 42-125.* (Presented at June 1942 Convention.)

AUTOMATIC RECORDING . . .

The rapid drawing of light-sensitive-cell characteristic curves accomplished automatically by the photoelectric recorder



By H. T. WROBEL
Meter and Instrument Laboratory, General Electric Company

Henry T. Wrobel

THE light-sensitive cell is a comparatively new development. As a result the present state of the art of manufacturing these cells results in a product which is not identical from unit to unit. This is a very important consideration when combining these cells with instruments to obtain a device to measure light.

The purpose of this article is to present a method that is of definite value in reducing the time required to study, on a statistical basis, the characteristics of these cells.

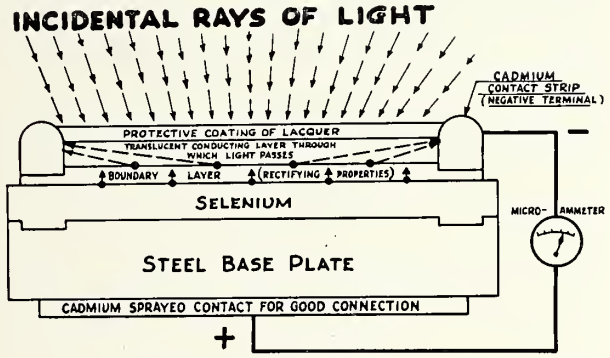


Fig. 1. Cross-section drawing showing the essential elements of the light-sensitive cell

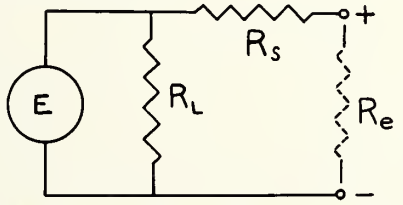


Fig. 2. Equivalent circuit of light-sensitive cell

E = Hypothetical generator
R_s = Internal series resistance
R_L = Internal leakage resistance
R_e = External load resistance

History

As a matter of perspective, a brief history reveals that in 1839, about a hundred years ago, E. Becquerel discovered that a difference of potential existed between two metal electrodes immersed in an electrolyte when one electrode was illuminated. This was one of the first observations of the phenomena of transformation of light to electricity.

In 1874 the light sensitivity of selenium was discovered, and in 1876 Adams and Day proved that a current was actually produced by the light falling on the metal electrode contact to a bar of crystallized selenium. The transformation of light energy into electrical energy is indeed fascinating and remarkable.

The appearance of the improved layer type of light sensitive cell, the typical construction at the present time, took place subsequently. Research and development for the purpose of further improving the cell are still being conducted.

Construction

In **Fig. 1** are shown the essential components of the light-sensitive cell. The supporting base and positive terminal of the cell is a rigid metal plate, usually of steel. On this base plate is a thin layer of selenium in its brittle crystalline form, which is highly sensitive to light. The top layer of the cell is a transparent conducting layer, which is the negative terminal, and between this conducting layer and the selenium is an extremely thin insulating layer.

Theory

For the purpose of the present analysis the process whereby light energy is transformed into electric energy may be explained by again referring to **Fig. 1**. The light being measured falls upon the transparent conducting layer and penetrates through to the surface of the selenium. There it excites electrons and gives them enough energy so that they penetrate the boundary or insulating layer and accumulate on the conducting layer.

The charge on the negative terminal, however, does not build up indefinitely, because the electrons leak back through the boundary layer when a difference of potential exists across this layer. Hence for a given illumination the difference of potential across the insulating layer reaches a value at which the electrons going in the two directions are in balance.

If the negative terminal is connected to the positive terminal, for example through a microammeter, a current flow will be indicated because the electrons have found another path to return from one side of the insulating layer to the other .

For further analysis as a basis of approach, the cell may be represented by an equivalent electric circuit. This circuit is shown in **Fig. 2**. E is a generator which is the source of the electric energy obtained from the light energy. R_L is the leakage resistance of the insulating layer, previously mentioned. And, R_S is the series resistance internal to the cell which impedes current flow when the positive and negative terminals are connected together. This series resistance consists of the transparent conducting layer which is necessarily thin, the layer of selenium itself which is only

a semiconductor, the contact between the selenium and base plate, and the resistance of the base plate itself which is negligible by comparison.

Determining Cell Characteristics Semiautomatically

In **Fig. 3** are shown typical curves of current output versus illumination. Each of these curves represents an individual cell, and they were plotted

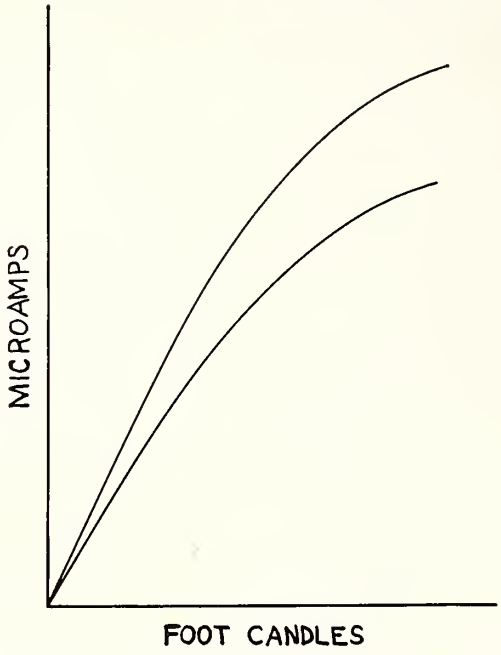


Fig. 3. Curves showing the variation in sensitivity between two cells

from data taken on two cells with the same external load resistance. This resistance corresponds to R_e in **Fig. 2**.

Fig. 4 shows curves similar to those in **Fig. 3**, but for various values of R_e as noted on the individual curves. It will be evident from a consideration of **Fig. 4** that a more nearly linear-scale characteristic will result for a D'Arsonval instrument operating from such a cell if the instrument circuit resistance is kept low. There are some variations in the shapes of curves for individual cells even with the value of R_e identical as was shown in **Fig. 3**.

It was, therefore, important to study a large number of cells in order to establish classifications or groupings of cells to fit within close-limit predetermined instrument scales for foot-candle meters. The apparatus used will be described as it resulted in a great time saving and did a precise job of measurement work.

This equipment, arranged to obtain automatically current-output versus external-resistance characteristics at constant illumination, is shown in **Fig. 5**. The three principal components in this arrangement are from left to right.

(1). A photoelectric recorder[1] which is capable of drawing an ink record with a requirement of only 50 microamperes for full-scale deflection. This recorder is shunted to obtain the desired full-scale microampere range.

(2). A photometer providing different values of constant illumination.

(3). A synchronous-motor-driven step resistance which varies logarithmically with time and which is the external-resistance load on the cell.

In operation the photoelectric recorder chart moves as a linear function of time. The time abscissa, therefore, becomes a resistance abscissa which varies logarithmically from 100 ohms to 10,000 ohms. Since the ordinate on the chart is current output, the recorded curve is a current-resistance characteristic. The time required to obtain such a curve is a little over one minute.

In **Figs. 6** and **7** the characteristics of two cells at 120 foot-candles, obtained in the above manner, are illustrated. It is of interest to note that the curve in **Fig. 7**, which drops in output more rapidly than the curve in **Fig. 6**, is an example of a cell with a lower insulating layer resistance (R_L in **Fig. 2**).

It is, of course, possible to alter the arrangement and vary the illumination as a function of time to obtain output illumination characteristics directly.

Several hundred cells were studied with this apparatus and basic design data were obtained.

(1) "High-speed Photoelectric Recorder," by H. L. Clark, GENERAL ELECTRIC REVIEW, vol. 45, p. 384, July 1942.
"An Improved Photoelectric Recorder," by C. W. LaPierre, GENERAL ELECTRIC REVIEW, vol. 36, p. 271, June 1933.
"The Photoelectric Recorder," by C. W. LaPierre, *Transactions, A.I.E.E.*, vol. 51, p. 226, March 1932.
"Application of the Photoelectric Recorder," by W. L. Carson, GENERAL ELECTRIC REVIEW, vol. 39, p. 189, April 1936.

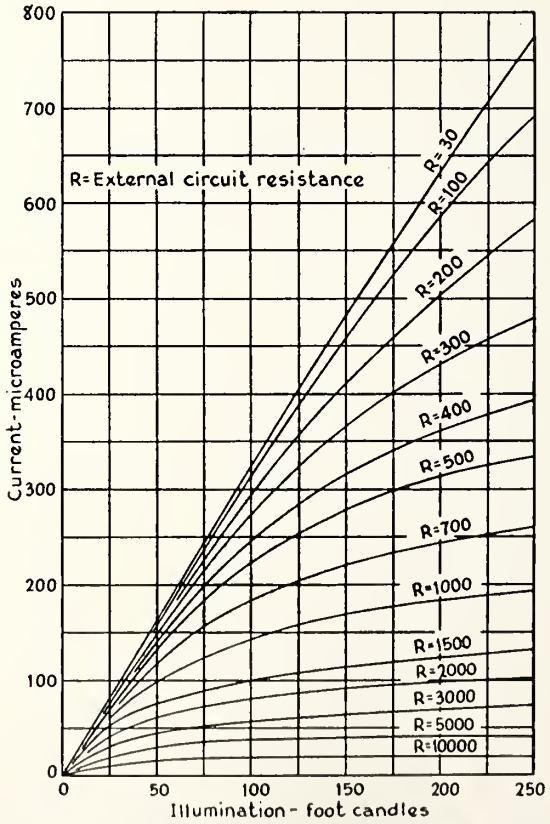


Fig. 4. Current output as a function of illumination and external circuit resistance (cell temperature, 25 C)

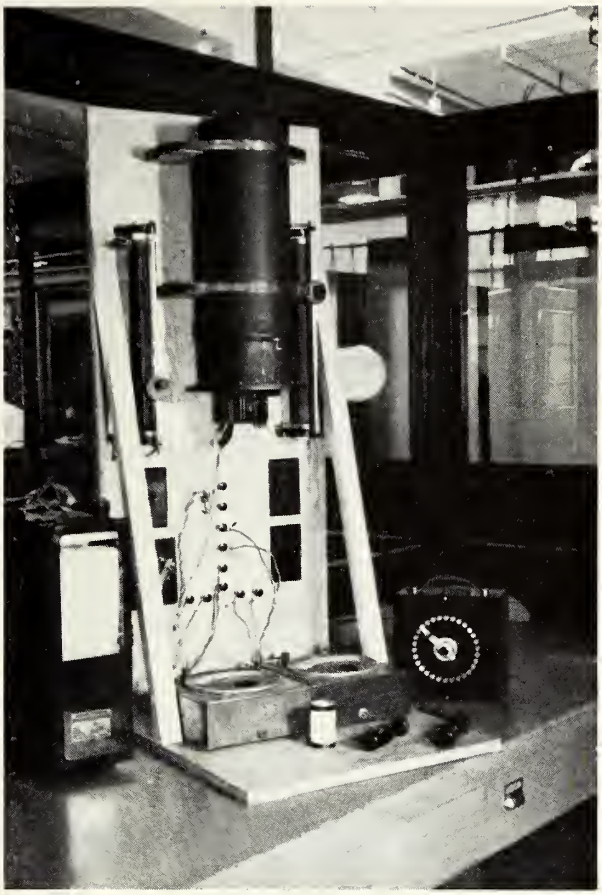


Fig. 5. Equipment used for automatically drawing cell characteristics

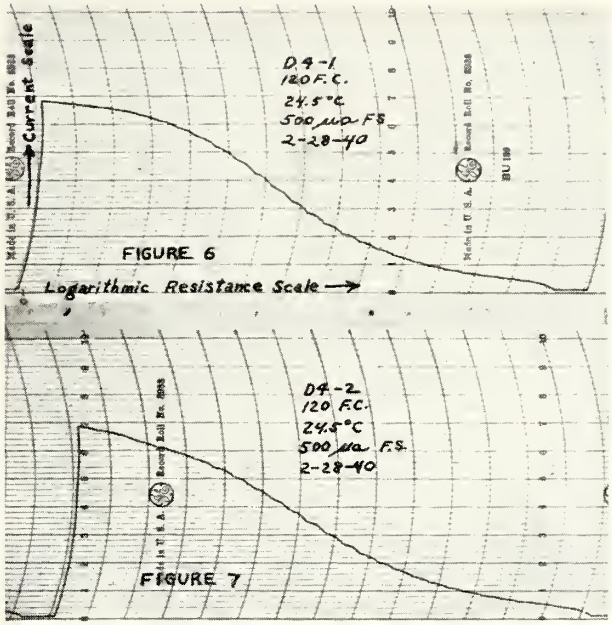


Fig. 6 and 7. Automatically drawn curves illustrating cell characteristics

Conclusion

The selenium photovoltaic cell has been studied by a semiautomatic measurement method which employs the photoelectric recorder to draw the actual curves of cell characteristics. A great deal of time was saved by this method and a complete study of the individual cell variations for the purpose of obtaining basic design data was made possible.

WATTHOUR METERS . . .

Large savings of critical materials through utilization of alternates

By G. R. STURTEVANT
Watthour Meter Engineering Department
General Electric Company

THE first successful commercial watthour meter for use on either alternating or direct current was completed and shipped on September 18, 1889. It was manufactured by the Thomson-Houston Electric Company, predecessor of the General Electric Company.

One of these early meters is shown in **Fig. 1**. It has a cast-iron base, a sheet-steel cover, a cast-brass frame, a brass register with a paper dial face, a copper disk, a steel shaft, and a slate terminal block.

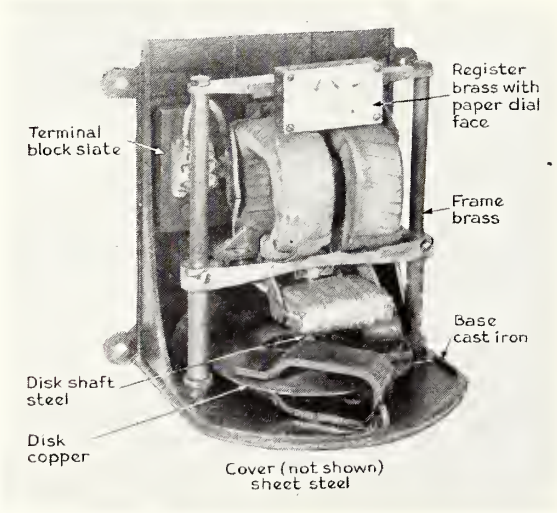


Fig. 1. The first commercial Thomson recording wattmeter (watthour meter)

Choice of Materials

Since September 18, 1889, the choice of materials to be used in the more than 22,000,000 meters manufactured by the General Electric Company has received a great deal of attention. This has been necessary in order to solve the many design problems encountered in meeting the needs of the utilities and public service commissions, during these more than 50 years of phenomenal growth in the use of electric energy.

The features required of these meters may be briefly listed as follows:

(1). A means of measuring true electric energy
(2). Sustained accuracy
(3). Smaller and less expensive meters
(4). Ease of adjustment and maintenance
(5). Full compensation for voltage, temperature, and load variations.
(6). Resistance to tampering and current diversion
(7). Weather resistance
(8). Long-range current capacity and accuracy
(9). Standardization of mounting dimensions.

All of these requirements have been answered in the best way possible through the years, by making use of new and better materials as they have been made available commercially. The results are evident in the small light-weight compact meter of 1939. By electrical design, it has the long-range current capacity and accuracy essential to metering of present-day loads. By mechanical design it is adequately protected against weathering and tampering to permit either indoor or outdoor mounting.

Applications of Aluminum

During these more than 50 years of progress, the application of aluminum to the watthour meter has probably been the most significant in the way of material changes. The first application was the replacement of copper in the rotor or disk of the meter unit. This was a natural change because of the extremely light weight and relatively high conductance of pure aluminum. This application not only decreased the possibility of bearing troubles, but it also permitted the design of a meter motor unit around the light-weight element to give the wide-limit meter of today and the excellent time-earned reputation of electricity meters for stability of calibration.

Other applications of aluminum came in the way of the die-cast base, cover ring and bayonet clips, sealing bar, disk shaft, register plates and parts, nameplates, sealing clip, and meter protective housings. The aluminum die casting was particularly well suited for the making of meter bases and housings due to its inherent resistance to corrosion and its moldability. The latter is essential in order to obtain the intricate shapes and close tolerances necessary in making these parts adequately weather and tamper resistant.

The Use of Alternates

During the past several years, however, world conditions have called for major changes in our ways of doing things. The supply of many materials has become very critical, and their uses have had to be

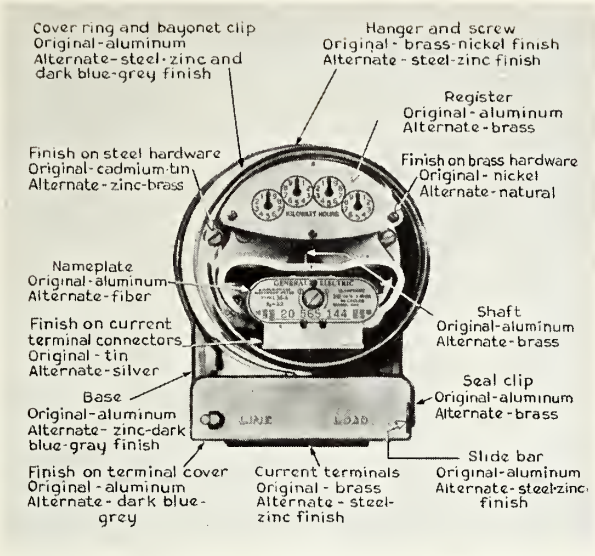


Fig. 2. A single-phase watthour meter showing the use of alternate materials

carefully directed. It has become imperative that natural resources be more carefully conserved than ever before, and in this connection it early became evident that the watthour meter, in measuring the electric energy consumed, would be an important factor in this vital program.

It thus became essential to find ways and means of using suitable but less critical materials than aluminum and copper which largely made up the modern watthour meter of 1939. A program for the trial and testing of alternate materials for the many parts was planned. Several were considered for each application and an alternate was used only after adequate tests to prove the suitability of the proposed material. In making a decision as to which alternate to use it was always necessary to keep in mind the probable availability of the alternate material at the time it would be needed.

Although aluminum was the most critical material used in quantity in watthour meters, substantial decreases were made in the use of copper. Also in smaller quantities, nickel, tin, cadmium, zinc, toluol, and formaldehyde were eliminated or replaced by suitable alternate materials.

The use of these materials in the single-phase Types I-30-A and I-30-S watthour meters is indicated in **Figs. 2** and **3**. The magnitude of this program and its contribution to the war effort can be best appreciated by referring to Table I.

Effects of Material Changes

The major point of interest now is the effect of all of these changes on the life and operating characteristics of watthour meters. **Figs. 2** and **3** indicate that with the exception of the change in material of the disk shaft and register parts, all the changes in the meter unit are changes in finish. In

TABLE I

ANNUAL SAVINGS OF ALUMINUM BY THE USE OF ALTERNATE MATERIALS IN WATTHOUR METERS

Component	Approx. Saving in Pounds
Bases	548,000
Cover rings and bayonet clips	191,000
Register parts	103,000
Meter frames	46,000
Miscellaneous hardware	32,000
Nameplates	15,000
Terminal covers	10,000
Disk shafts	3,600
*Accessories (cases and boxes)	313,000

*Line discontinued.

general, the finishes now used are what we might call obsolete finishes and were earlier superseded mainly on the basis of improved appearance. These should, therefore, not be a source of difficulty.

The use of brass for the disk shaft does increase the weight of the moving element slightly. This should cause no particular difficulty, however, since the percentage increase in weight of the moving element is quite small. Also, there is no appreciable change in the operating characteristics of the meters.

In regard to the meter unit housing, which includes the base, cover, and miscellaneous hardware, it is believed that the best possible use has been made of the available materials. Protective finishes consisting of both electroplating and lacquering amply protect the parts made from these materials.

Conclusion

In conclusion it can, therefore, be said that many changes have been made in the materials used in watthour meters, and substantial quantities of the most critical materials have been released for direct war purposes. These changes, however, have not detracted from their accuracy and practical utility in the measurement and conservation of electric energy which is so vital to our war effort.

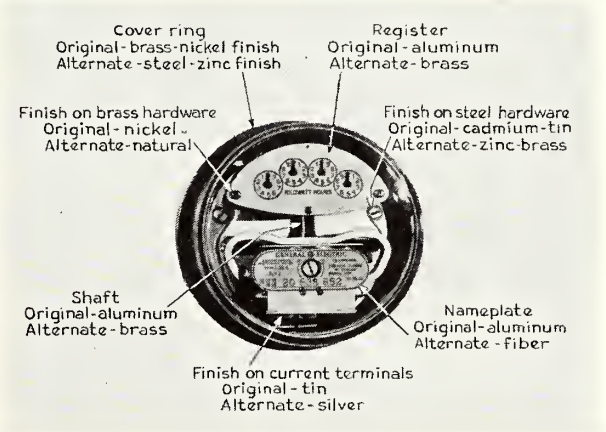


Fig. 3. Another type of single-phase watthour meter illustrating the use of alternate materials

INFLUENCE OF MEASUREMENTS ON DEVELOPMENT OF MAGNET WIRE

By F. P. WILSON, Jr. and J. A. WEH
Insulation Engineering Department General Engineering Laboratory
General Electric Company

RESEARCH advances knowledge. Measurements and their interpretation through engineering development advance progress. For instance, research provided Formvar resin, and the development, application, and interpretation of measurements set the stage for its effective use as the insulation for Formex wire.

Importance of Magnet-wire Measurements

The trend in electrical-apparatus design is toward placing greater reliance on magnet-wire films without the use of additional coverings of cotton or paper. The load which such films must carry emphasizes the need for adequate and significant test methods, particularly those which reveal physical properties.

New Methods of Measurements

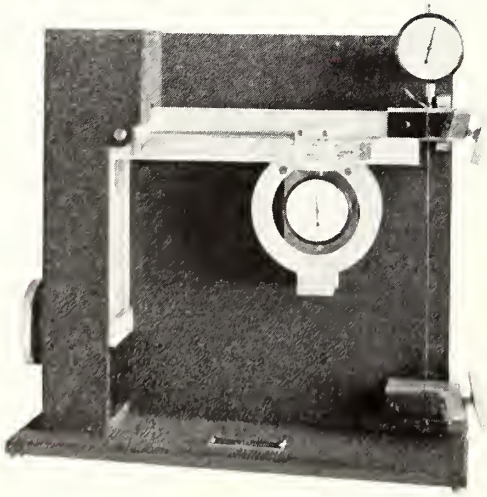
New methods of measurement for magnet wire have been previously described in the GENERAL ELECTRIC REVIEW.

Their use encouraged large-scale trials of Formex wire and a new philosophy of electrical-apparatus design.

The subsequent acceptance of such philosophy by the industry is a tribute, not only to Formex per se, but also to the accuracy of early predictions based on measurements.

Selection of Magnet-wire Insulation

The great variety of synthetic resins now available as potential wire coverings adds to the problem of selection. The problem is simplified through the use of measurements to indicate essential properties which can be interpreted in terms of practical wire usage.



With this tester the degree of anneal of the copper wire or the copper stiffness can be measured in terms of the permanent deformation in a 10-in. gage length caused by a tensile stress of 10,000 lbs per sq in. cross-sectional area.

Fig. 1. Low-stress elongation wire-stiffness tester

The development of new measurements made it possible to select Formvar resin, assess its potential value and ultimately delineate its field of use. The knowledge thus provided enabled us to persist in and concentrate effort on that material having the most favorable characteristics.

Guiding the Development of New Wire Insulation

Measurements are commonly thought of as a means of control in conformance with known requirements or values. As a means also to successful research and development, the importance of measurements and their interpretation are often overlooked in the enthusiasm for a new product or the creative technology which achieves it. Perception so vitally important in development work is aided in reducing that work to practical use by the application and interpretation of measurements.

Changes in wire-insulating materials achieved through chemistry must be guided and their ultimate value determined by measurements on the *finished wire*. This is necessary because of the intimate relationship between wire-insulating materials and methods used to apply them.

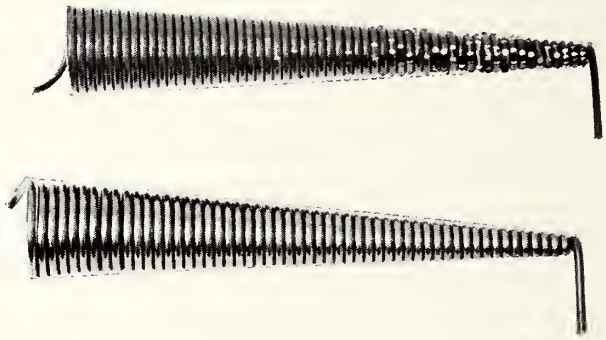


Fig. 2. Tapered mandrel test helices

By bending the wire around the tapered mandrel in the form of a helix a range of elongation is obtained in the outer surface of the wire according to the following relation $E = \frac{100}{\frac{D}{d} - 1}$, where E is the per cent elongation, D is the over-all diameter of the helix turn, and d is over-all diameter of the wire. Observation of the elongation at which the film cracks is thus a measure of the film flexibility or heat shock after helices are heated.

The wire-enamel chemist, for example, would be seriously handicapped if measurements applied to magnet wire failed to indicate the effect of change or interpret needed improvements.

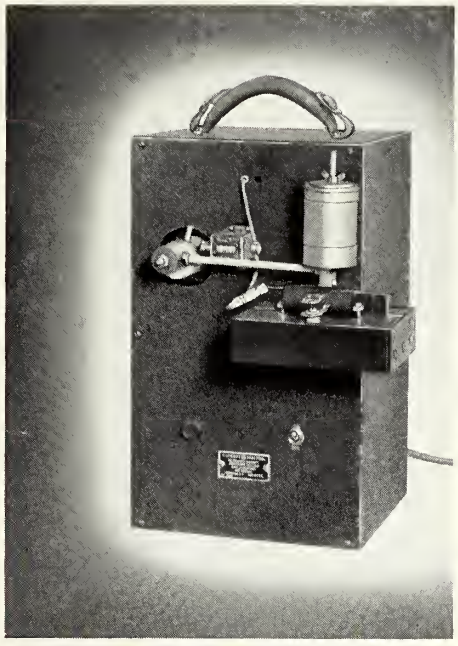
Transition of Wire Developments from Test Tube to Production Use

The transition of research and development into production use presents many problems. It is during this transition that a product may fail, encounter serious delay or faulty field performance unless precise and adequate measurements have been made in advance to assist in predicting behavior.

Although Formvar resin was available several years before it was applied as a wire covering, the

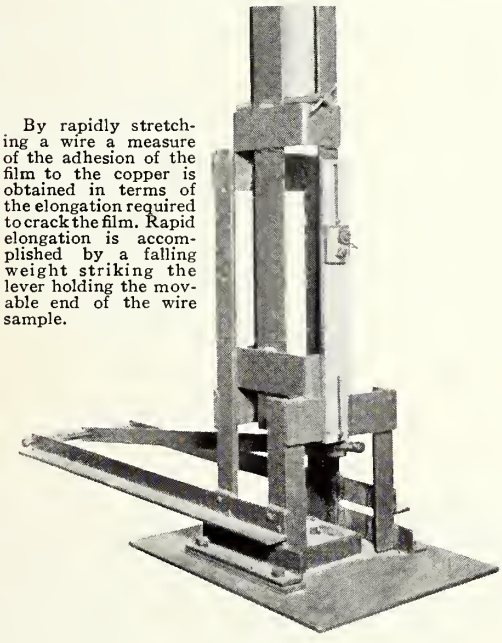
interim progress in measurements and the recognition of needs and opportunities which they provided, stimulated interest in this material and set the stage for Formex wire production.

Specifications supported by methods to measure what is specified, guide the production of wire. Without measurements, specifications would be useless and consistent reproduction would be impossible. Thus the effectiveness of transition from test tube to production is largely proportional to the adequacy and utilization of measurements.



By repeatedly scraping the film on the wire with a definitely shaped abrasion edge this device measures the film toughness in terms of the number of scrapes required to wear through to the copper. By the selection of the scrape pressure, test time can be controlled within sensible limits for good or poor films.

Fig. 3. Repeated scrape-abrasion tester



By rapidly stretching a wire a measure of the adhesion of the film to the copper is obtained in terms of the elongation required to crack the film. Rapid elongation is accomplished by a falling weight striking the lever holding the movable end of the wire sample.

Fig. 4. Snap elongation tester

Quality Control

Having chosen an available wire insulation or developed a new one, and having written suitable specifications, the problem remains to consistently meet the requirements of such specifications. Therefore, each step in the process from raw material to finished product must be not only covered by specifications but checked by measurements.

The problem of quality control is complicated during periods of change brought about by progressive developments or material substitutions caused by war, which has accelerated the normal trend toward the use of adequate, but not excessive, safety factors consistent with needs.

Shortages of materials, combined with a continuing if not greater need for quality, emphasize the importance of measurements as a guide to design. In general, however, improved quality and lower costs can both be achieved, since measurements aimed at quality control permit adjustments in material and wire manufacturing methods to be made with confidence.

Aids in Design and Application

The latest methods of measuring the properties of magnet wire in developmental work are given in Table I.

The high viscosity of Formvar enamel has necessitated the use of wiping dies during the manufacture of Formex wire. This viscosity aggravates the problem of producing wire with a concentric film and emphasizes

TABLE I

WIRE PROPERTIES AND MEASUREMENTS

Wire Properties	How Measured
(1) Copper stiffness	With the use of the low stress elongation wire stiffness tester shown in **Fig. 1.**
(2) Appearance and color of the enamel film on the wire	By visual inspection.
(3) Wire dimensions Film thickness Film concentricity	With machinists' micrometer caliper measurements. By microscopic inspection of polished cross-sections or with the use of the capacitance concentricity tester.
(4) Film toughness	
(a) Flexibility at room temperature	By noting the elongation required to crack film using tapered mandrel helices shown in **Fig. 2.**
(b) Heat-shock resistance at coil-treating and operating temperatures	By noting cracking of tapered mandrel helices after heating. Shown in **Fig. 2.**
(c) Abrasion resistance	With the use of the repeated scrape-abrasion tester shown in **Fig. 3.**
(5) Adhesion of film to wire	With the use of the snap elongation tester shown in **Fig. 4.**
(6) Resistance of film to thermo-plastic flow	With the use of the compression-flow tester shown in **Fig. 5.**
(7) Inertness to solvents, varnishes and treating compounds	By observation of changes in film due to immersion in these materials.
(8) Inertness to water, weak acid and alkalies, and oils	By change in dielectric breakdown due to immersion in these materials.
(9) Inertness to heat aging	By change in film flexibility with heat aging.
(10) Dielectric breakdown of the enamel film	By short-time dielectric breakdown test.
(11) Film continuity	With the use of the film continuity tester shown in **Fig. 6.**

the importance of a control device* developed for measuring film concentricity.

A hot-solvent test was developed to measure not only the resistance of Formex wire to subsequent varnish treatments, but also to check the adequacy of control applied to the manufacture of the Formvar resin as well as to check the selection of the raw materials.

Heat shock is an old weakness in enameled wires which caused a film under tension to crack when heated, thus necessitating supplementary protective insulation. The first known appearance of heat shock in a specification, however, followed the development of Formex wire. Resistance to heat shock is one of the most significant properties of Formex wire revealed by new measurements. It indicates film elasticity maintained under temperature and tension. Thus, heat-shock resistance, with film toughness, first established Formex wire as a radically new product with promising design possibilities.

A new device for measuring scrape-abrasion resistance indicates the toughness of the film and its ability to withstand high-speed winding methods, while a new measurement for wire stiffness permits the establishment of elongation tolerances to meet winding requirements. Resistance to excessive stretch or flexibility to avoid springiness may be required. Excessive stretch not only affects the insulating film but also, because of reduction in copper diameter, it nullifies design calculations based on initial wire dimensions.

Wire users have awakened to the importance of adequate measurements and are demanding higher quality. This is exemplified by the new standards shown in Table II. Without new methods of measurement, such new standards could not have been determined, maintained or interpreted to potential users.

Measurements and their interpretation also suggested a practical solution to the Formex wire crazing mechanism which causes a film under tension to develop hair-line cracks when immersed in many solvents or liquids. Ability to measure the plastic flow of the Formex wire film permitted the setting of temperature limits during varnish treatment and baking to avoid flow of the film.

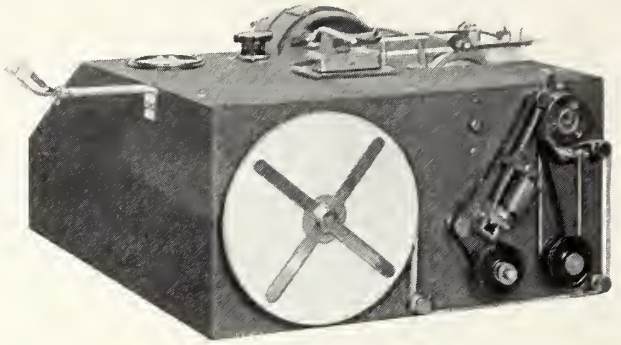


Fig. 6 Film continuity tester

By drawing the wire through a mercury bath with an electrical stress between the wire and the bath, discontinuities in the wire film are indicated and recorded with this tester.

Further improvements in magnet wire, and consequently in the apparatus into which it is wound will be aided by methods of measurement now available and under development. "Cut and try" has definitely given way to methods of appraisal which make comparisons possible in less time and with more significance, more accuracy, and more confidence.

TABLE II

STANDARDS OF QUALITY

Here tabulated are some of the more important properties of magnet wires.

Film Property	Old	New
Flexibility—Per Cent Elongation to Crack Film at 25 C	35–50	70+
Heat Shock—Per Cent Elongation to Crack Film at 150 C	12–20	70+
Heat Aging at 125 C—Relative Aging Time to Embrittle Film to Crack on 25 Per Cent Elongation	1	10
Abrasion Resistance—Relative Number of Scrape-abrasions to Wear Through Film	1	30
Solvent Resistance—Relative Time to Soften the Film on Wires Immersed in Petroleum Solvents	1	3

(*)See article "Concentricity," by E. F. Hansen, appearing on page 61.

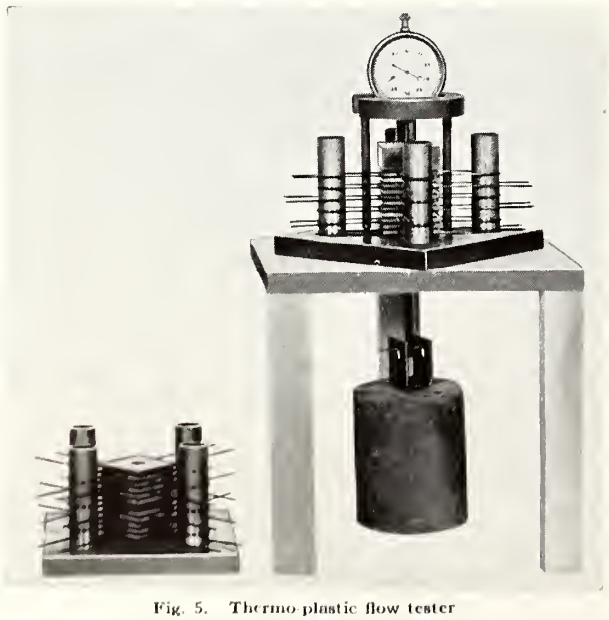


Fig. 5. Thermo plastic flow tester

The resistance to thermo plastic flow can be measured with this tester in terms of the decrease in diameter of the wire under known compression and temperature.

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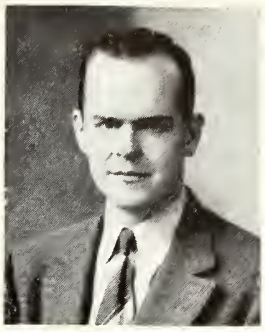
CONCENTRICITY . . .

Testing concentricity of enamel film on round wire is now made rapid by the development of a special tester utilizing electronic circuits

By E. F. HANSEN
Thomson Laboratory, General Electric Company



Elmer F. Hansen

THE insulating film on round enameled magnet wire at any cross section should be concentric about the conducting core. At the times when wire-coating machinery is undergoing adjustment, tests must be made to check the concentricity of the coating of film. Since various other laboratory tests are made to determine abrasion resistance and dielectric strength of the enamel insulation, the results of these tests are naturally affected by the thickness and concentricity of the insulation.

Probably the most reliable method of determining film thickness and concentricity is to examine the wire cross section with a microscope. In order to do this, it has been customary to mount a sample of the wire in Woods metal and then carefully polish the cross section. The film thickness may then be measured by means of a measuring microscope or photomicrograph. These methods consume much time, however, and are not convenient when a large number of samples are to be checked.

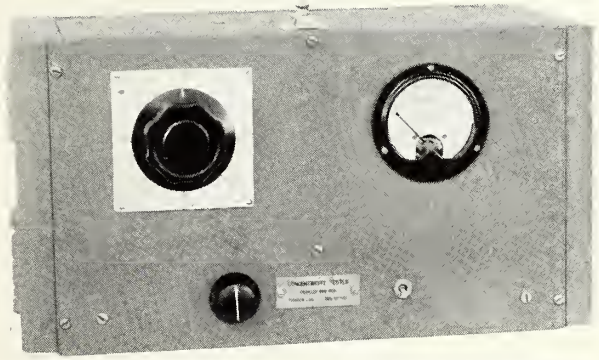


Fig. 1. Front view of the device for testing the concentricity of enamel film on wire

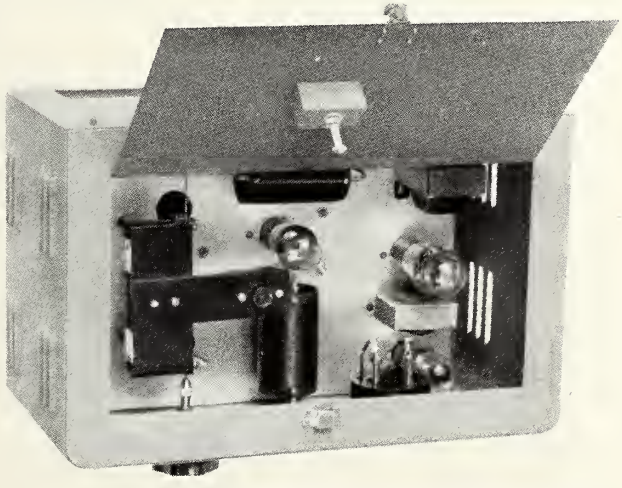


Fig. 2. Top view of the tester with cover open to show interior

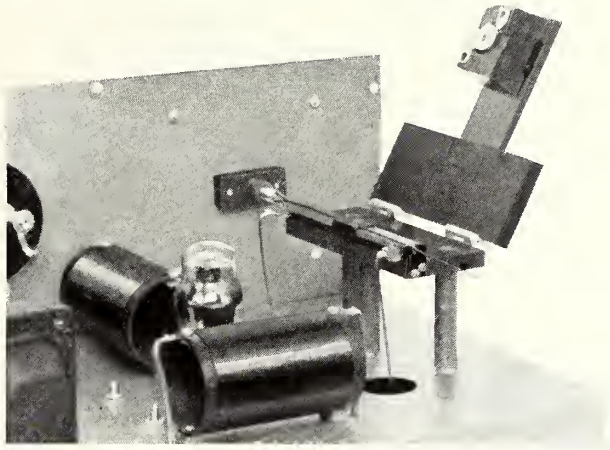


Fig. 3. View showing the wire sample in position on the brass plates, and the hinged means of holding it flat when the cabinet is closed

The tester described in this article was developed to fill the need for a quicker and more convenient method of checking enameled-wire concentricity. Its principal application has been in the laboratory and it has become a useful addition to the existing wire-testing devices which are designed to maintain quality in wire production.

Operation

Front and top views of the tester are shown in **Figs. 1** and 2. With the cover lifted, a seven-inch sample of wire is inserted in a turning chuck and placed in position on brass plates between the guides provided. A hinged insulating block, shown in place in **Figs. 2** and 3, applies pressure to hold the wire flat on the brass plates. The wire sample is rotated by the large knob to get minimum deflection of the indicating instrument. The sensitivity of the tester is then varied with the small knob until a reading of 1.0 on the indicator scale is obtained. The wire is then rotated to get maximum deflection. The latter reading is a measure of concentricity in units of ratio of maximum to minimum film thickness.

The tester is self-contained in a metal-shielded cabinet and operates directly from 115-volt 60-cycle mains. A gaseous regulator tube assures readings which are independent of fluctuations in line voltage. Circular enameled wire of 0.025 to 0.065 in. diameter with a film thickness of about 0.001 to 0.006 in. can be tested. The time required for testing a sample is about one minute.

Fig. 4. Photomicrograph of nonconcentric enamel film (cross section magnified 50 ×)

Principle of Operation

The tester operates on the fundamental electrical principle of proportionate increase in capacitance of two conductors as the thickness of the dielectric between them decreases. A brass plate is one of these conductors, the film of enamel is the principal dielectric, and the copper core of the wire is the second conductor. The tester uses a series connection of two brass plates in the same plane per sample of wire and thus eliminates the necessity for scraping off insulation.

An example of nonconcentric wire is shown by the photomicrograph in **Fig. 4** which is magnified fifty times. The capacities of selected wire samples with varying degrees of concentricity were found to be in the region of 5 to 7 micromicrofarads. The corresponding insulating film varied from 0.004 to 0.001 in. thick.

In order to get the required sensitivity, a high-frequency (900-kc) current is used in the indicating circuit. A tuned-grid tuned-plate oscillator is employed to generate the high-frequency current. The circuit is shown in **Fig. 5**. The capacitance of the wire sample C_1 shunts the grid-plate interelectrode capacitance of the type 37 triode oscillator tube V_1. If the wire is not concentric, its rotation will change the capacitance and thus vary the coupling between the grid and plate circuits of the oscillator. An increase in the film thickness was found to cause a proportionate decrease in capacitance. A decrease in capacitance, and consequently in coupling between grid and plate circuits, results in an inversely proportionate increase in the d-c plate current drawn by the oscillator tube, a characteristic of vacuum-tube oscillators. An increase in film thickness, therefore, is indicated by an increase in the deflection of the milliammeter M_1 which reads d-c plate current.

The deflection was found by test to be a linear function of the film thickness over the used portion of the scale. This proportionality was verified and the milliammeter scale temporarily calibrated in mils thickness by means of measurements on photomicrographs of cross sections of many wire samples. To get a linear calibration, it was found necessary to tune the grid circuit to the third-harmonic frequency of the plate circuit. The sensitivity control regulates the per cent change of deflection per unit change of insulation thickness. It makes possible the present calibration in units of ratio, and consists of a very small variable capacitor C_2 shunted across the wire capacitance.

The calibration in units of ratio of maximum to minimum film thickness remains accurate even though some of the circuit parameters and frequency of

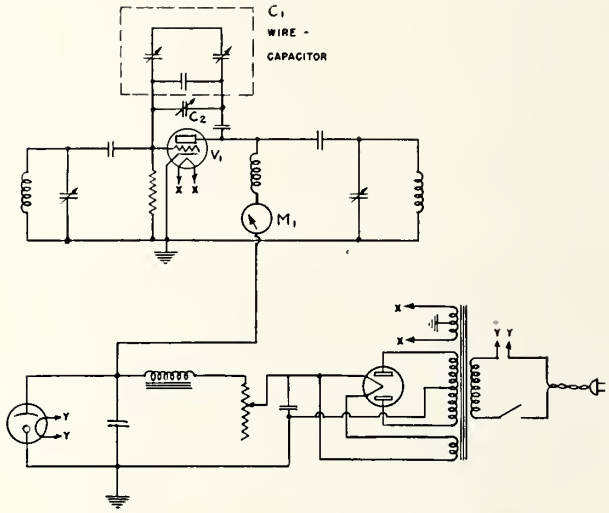


Fig. 5. Circuit diagram of the concentricity tester

oscillation change slightly. If the calibration were directly in mils thickness of insulation, adjustment and recalibration would be necessary when certain circuit components changed a small amount in value due to temperature, aging, or other effects. The average error in measurement of ratio was found to be about 5 per cent for all sizes of wire measured. A maximum error of 13.5 per cent was observed. The larger errors are caused, it is believed, by slight twists in the wire samples, and in some cases by change in concentricity along the length of the sample.

This device rapidly and reliably furnishes test measurements used in making wire-coating machinery produce concentric film. The tester has also been helpful in the laboratory when used in conjunction with other types of wire-testing apparatus.

HIGH FREQUENCIES . . .

The status of high-frequency standards and measurements

By H. R. MEAHL
General Engineering Laboratory, General Electric Company

Harry R. Meahl

THERE are only two standards which can properly be called high-frequency standards: one is the crystal-controlled oscillator maintained by the United States Government and used to control the emissions of radio station WWV, and

Fig. 1. The wide-band cathode-ray oscilloscope

the other is the high-frequency electrodynamic ammeter.[1]

The former is really a secondary standard, but that does not mean it lacks accuracy. In fact, it is one of the most accurate standards in the world, having an average frequency which is correct within one part in ten million. The crystal-controlled oscillator is compared to the time standard, the rotation of the earth, by using multivibrators, electronic gears, to make it control a clock which when checked by astronomical observations gives the rate of the crystal; i.e., if the clock gains, the crystal frequency must be high by a proportionate amount and vice versa.

The latter is a primary standard under the definition that a primary standard is one whose operation can be predicted from measurements of length, mass, and time.[2] Its accuracy, therefore, depends upon the accuracies of these three fundamental standards and upon the care with which the measurements of length, mass, and time are made. Therefore, measurements based upon either of these standards may be made to compare favorably with any measurements at any frequency, even zero frequency, i.e., direct current.

Unknown frequencies from thousandths of a cycle per second to thousands of millions of cycles per second can be measured accurately in the laboratory. This fact makes it highly desirable to use methods of measuring which make frequency the pointer on the instrument, so to speak. For example, if a small capacitance or small change in capacitance is to be measured, the best way to do it is to connect the capacitor across the tuned circuit of a self-excited oscillator, observe the resulting change in operating frequency, and calculate the capacitance change. By proper choice of circuit constants a "capacitance microscope" can be made in which thousandths of a micromicrofarad become relatively large as "seen" in the changes of frequency which they cause.

Even though many things can not conveniently be referred to the standard of frequency, they can be measured with acceptable accuracy by making use of the instruments and techniques available. The properties of a resonant or tuned circuit have been successfully used in making measurements of frequency, capacitance, inductance, and resistance over the frequency range of 60 cycles per second to 300 megacycles per second using "lumped" circuit elements, i.e., ordinary capacitors and coils. They have been applied over the frequency range of 100

(1) "Electro-dynamic Ammeter," by H. M. Turner and P. C. Michel, *Proc. IRE*, vol. 25, pp. 1367-74, November 1937. "Electro-dynamic Ammeter," by Harry R. Meahl, *Proc. IRE* vol. 26, pp. 734–44, June, 1938.

(2) Curtis, *Electrical Measurements*, p. 1, McGraw-Hill, 1937.

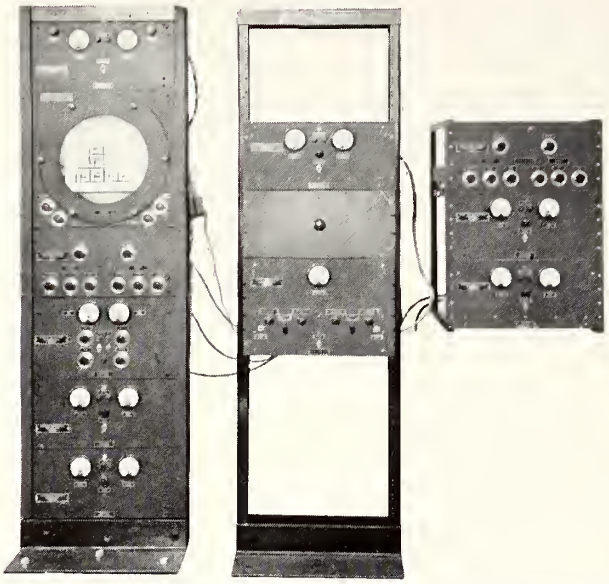


Fig. 2. Special-purpose television oscilloscope for testing characteristics of cathode-ray tubes: (*left*) television monitor; (*center*) synchronizing-pulse generator, and regulated power supply; (*right*) cathode-ray-tube deflection unit, and regulated power supplies

to 3000 megacycles per second by using transmission-line elements, and from 1500 to 5000 megacycles by using wave-guide elements. The measuring apparatus dependent upon the phenomenon of resonance for operation vary from a capacitance-measuring equipment, suitable for the rapid testing of capacitors in a factory, to vector-impedance measuring equipment, which requires trained operators to manipulate it and a mathematician to interpret the data in terms of the properties of a material under test.

There are more instruments available today than ever before and more are being developed. A great impetus was given to the development of measuring equipment by the developments of television and FM broadcasting, but a still greater one is now operating because of the war.

Some idea of the status of measurements at high frequencies can be obtained from the following listing:

Fig. 1 shows the wide-band oscilloscope which provides means for measuring voltage amplitudes from millivolts to hundreds of volts over the frequency range of 10 to 8,000,000 cycles per second. At the same time it shows the wave shape of the voltage and thereby conveys much information to the experienced eye. When provided with a servo-sweep, this instrument gives a clear image of a pulse less than one microsecond wide.

Fig. 2 shows a special-purpose oscilloscope designed to test the characteristics of the cathode-ray tube itself.

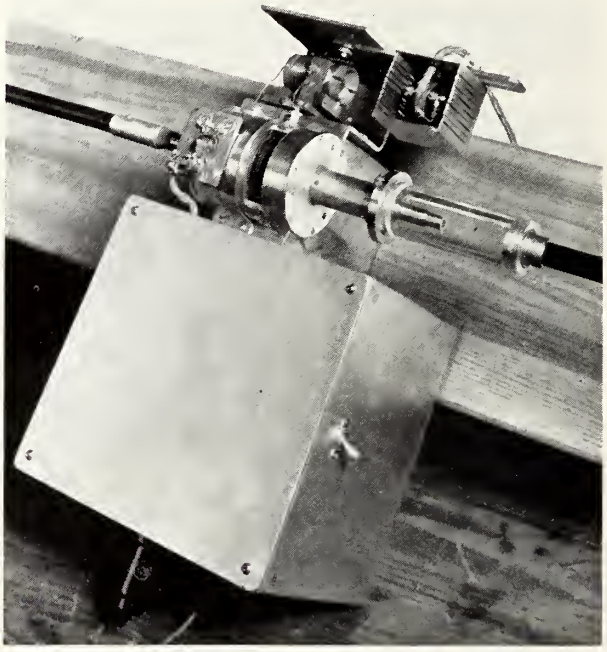


Fig. 5. The dielectric-power-factor measurement equipment

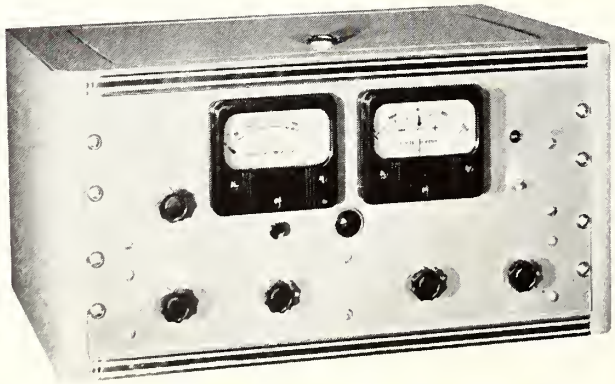


Fig. 3. The frequency-modulation radio-station monitor

Fig. 4. Portable ultrahigh-frequency field-intensity recorder

An FM station monitor is shown in **Fig. 3**. It measures the center frequency of an FM broadcast transmitter during regular operation with an accuracy of 0.0002 per cent, or within 100 cycles at 50 megacycles per second. Its normal range is 42 to 50 megacycles and some have been modified and operated at frequencies up to 72 megacycles. When used with a frequency converter they operate over the frequency range of 260 to 350 megacycles. In addition to giving a visual indication of frequency deviation, this device indicates per-cent modulation and gives a warning when a predetermined per-cent modulation is exceeded.

In **Fig. 4** is a portable field-intensity recorder which operates over the frequency range of 26 to 158 megacycles, and both indicates and records the field

strength of the received signal. It, like all field-intensity meters, is a calibrated receiver, and operates over a voltage range of from 15 microvolts per meter to 3 volts per meter. When the recorder is driven from the speedometer shaft in an automobile, a plot of field strength vs. distance is obtained. It can also be used as a radio-frequency voltmeter.

Fig. 5 shows dielectric-power-factor measurement equipment designed for use over the frequency range of 1 to 100 megacycles per second to determine the suitability of materials for use as insulators in this range.

The diode voltmeter in **Fig. 6** is designed to use in measuring the attenuation in coaxial cable at about 300 megacycles by noting the ratio of output-to-input voltage over a range of frequency when the cable is terminated. Of course, it may be used for other voltage or voltage-ratio measurements.

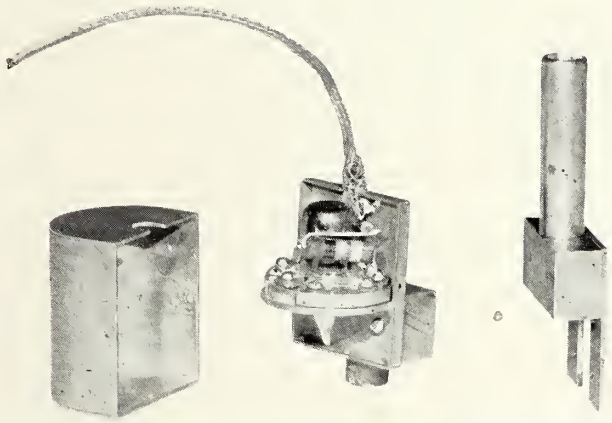


Fig. 6. Component parts (including fitting for joining two lengths of cable) of the diode voltmeter for cable attenuation measurements

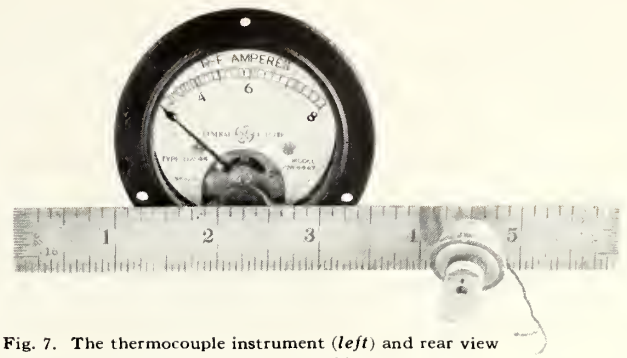


Fig. 7. The thermocouple instrument (*left*) and rear view of thermocouple assembly

Last, but not least, is the low-impedance thermocouple ammeter in **Fig. 7**. The thermocouple is semiconcentric and has only 0.005-microhenry inductance. The instrument shown has been calibrated over the frequency range of 1 to 200 megacycles by means of an electrodynamic current standard. It had a correction factor of 0.74 at 200 megacycles. A 0.75-ampere instrument of the same design has been calibrated by the same means up to 350 megacycles where it had a correction factor of 0.90. These instruments have the same accuracy, 2 per cent, as their low-frequency counterparts.

In conclusion, it is believed that high-frequency standards are well proved in, and it is known that measuring instruments for use at high frequencies are multiplying at a high rate. Wavemeters, standard signal generators, power-measuring instruments, power-factor and dielectric-constant measurement apparatus and equipment for measuring attenuation in coaxial lines and impedance in the microwave range are now available or are being developed.

CABLE TESTING . . .

Measuring the electrical properties of cables and insulating materials at high and ultrahigh frequencies

By H. C. ANDERSON
Bridgeport Works Laboratory, General Electric Company

THE increasing demand for the measurement of the electrical properties of insulating materials at the high and ultrahigh frequencies has caused a rapid expansion of the test facilities at the Bridgeport Works during the past year. This article will describe equipment used to measure the surge impedance of cables at one megacycle, attenuation losses of twin-conductor transmission cables at 300 megacycles, and attenuation losses of coaxial cables at 300 megacycles. The measurement of the power factor and the dielectric constant of molded-slab samples by the susceptance-variation method is also described.

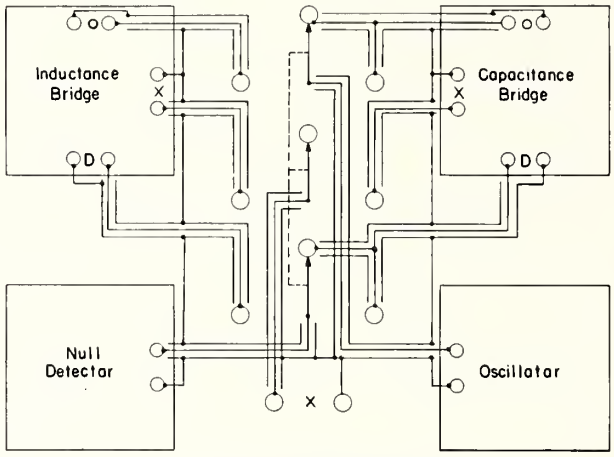


Fig. 1. The switching arrangement for the one-kilocycle cable-testing equipment

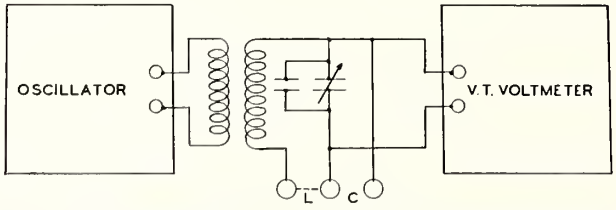


Fig. 2. Wiring diagram of the resonant circuit in the one-megacycle cable-testing equipment

Surge Impedance

At first the test equipment used to measure the surge impedance of coaxial cable was so assembled that it was necessary to change the cable connections from the capacitance bridge to the inductance bridge. To facilitate the measurement of these values from test samples of production cables, the one-kilocycle bridges and null indicator were assembled within a wooden framework. The null detector, a cathode-ray oscilloscope connected to indicate Lissajou figures, not only indicates the bridge balance but also the cause of trouble when either a shorted cable is connected to the capacitance bridge or when an open cable is connected to the inductance bridge.

The frequency source to the bridges is a multivibrator-amplifier circuit controlled by an inductance-capacitance circuit in resonance at one kilocycle. This frequency source is located behind the assembly.

To reduce terminal connections, the switching arrangement in **Fig. 1** is used. The three-position three-pole switch changes the sample, null detector, and frequency source from one bridge to the other. When the switch is at the mid-position the capacitance bridge is free to allow the setting of zero balance.

The surge impedance at both one kilocycle and one megacycle is calculated by use of the approximate formula:

$$Z_0 = \sqrt{L/C}$$

where Z_0 is in ohms
L is in henries
C is in farads.

The one-megacycle equipment is of the resonance type. It consists of a one-megacycle oscillator loosely coupled to a resonant circuit. A vacuum-tube voltmeter is connected to indicate resonance. The wiring diagram of the resonant circuit, used to measure the capacitance and inductance values of cable samples approximately five feet long, is shown in **Fig. 2.** The capacitance is determined by the difference in the resonance settings of the standard capacitor, first without and then with the sample connected to the capacitance terminals. In practice the average value for capacitance setting at resonance is used. It is determined by taking two readings, one with the vacuum-tube voltmeter indicating at a cardinal point under the peak value below resonance; the second

reading at the same cardinal point after the capacitor is tuned from below, through, to above resonance.

The inductance at one megacycle is determined by the use of the formula:

$$L = \frac{C_1 - C_2}{39.5\ C_1 C_2}$$

where L is in henries when the frequency is one megacycle

C_1 is the resonance capacitance in micro-microfarads of the resonant circuit

C_2 is the resonance capacitance in micro-microfarads with the sample connected

To increase the spread between two readings of C_1 and C_2 on the capacitor dial, a 2000-microfarad mica capacitor was paralleled with the standard capacitor. The power factor of this mica capacitor causes the measured value of the inductance to be in error by two per cent. To lessen error from change in oscillator frequency, frequent comparisons are made by beating the fifth harmonic of the oscillator against the signals of radio station WWV.

When measuring coaxial-cable samples at both one kilocycle and one megacycle, differences in test values are found. When copper-clad steel is used for the center conductor, the surge impedance is reduced as much as thirty per cent at the higher frequency because of skin effect, while a cable with a center conductor of 18 solid copper changes only two per cent.

Susceptance-variation Method

The power factor and dielectric constant of molded-slab samples of experimental compounds are measured by the change of capacitance procedure of the susceptance-variation method. The assembled equipment is shown in **Fig. 3**. The test sample in the foreground is polystyrene. The oscillator, which is designed to give frequencies from 42 to 70 megacycles, is housed in the cabinet to the rear of the test sample, while to the right of the sample is the resonant-circuit assembly and vacuum-tube voltmeter. A second test

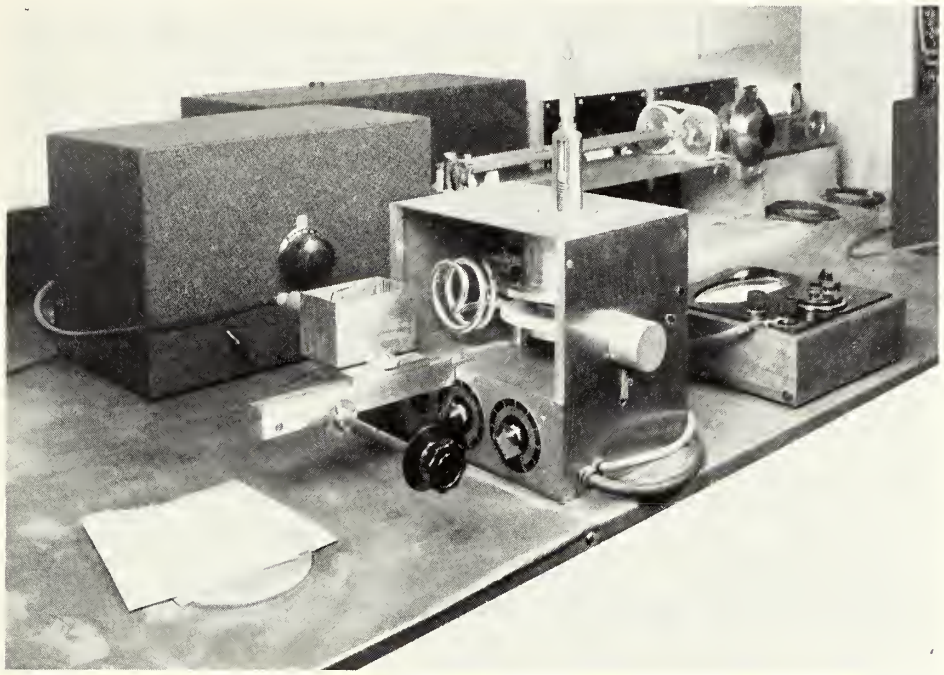


Fig. 3. Equipment used for the susceptance-variation testing method. (*Left to right*) Test sample, 42–70 megacycle oscillator, resonant-circuit assembly, and vacuum-tube voltmeter. Note test sample between electrode faces which form the capacitor of resonant circuit

TABLE I: TYPICAL DATA SHEET

	Data Sheet Heading	Data	
	Date.....	5/16/42	5/16/42
	Sample.....	1	2
	Temp.....	25 C	25 C
	Freq. mc....	47.7	47.2
Sample in			
Sample gap in mils...	M_s	162.6	148.2
Vernier mils at resonance.....	m_{s0}	500.5	502.5
Vernier mils .707 above resonance...	m_{s2}	529.2	521.1
Vernier mils .707 below resonance...	m_{s1}	481.4	489.0
Sample out			
Air gap in mils at resonance.....	M_{a0}	60.8	56.5
Vernier mils .707 above resonance...	m_{a2}	518.0	518.6
Vernier mils .707 below resonance...	m_{a1}	490.0	490.6
Calibration of electrode for M_a....	C_r	35.75	36.70
C_r – edge correction at gap of M_s.....	$C_x = C_r - A$	12.28	13.15
B = air capacitance of electrodes at M_s...	$K = C_x/B$	2.48	2.34
$m_{s2} - m_{s1}$.....	$\triangle m_s$	47.8	32.1
$m_{a2} - m_{a1}$.....	$\triangle m_a$	28.0	28.0
	$\triangle m_s - \triangle m_a$	19.8	4.1
$.0078 \triangle m_s - \triangle m_a$.....	$\triangle C$	.0990	.0205
	$2C$	24.56	26.30
tan $\delta \cong$ power factor when less than .1..	$\triangle C/2C_x$	.0040	.00078
$K \times$ power factor.....	L.F.	.0100	.00182

sample has been plaeed between the eleetrode faces which form the capacitor of the resonant eireuit. A small micrometer vernier eondenser is loeated at the right of the electrodes but is hidden by the assembly. Still further to the right is the mieroammeter which is ealibrated to determine the input voltage to the vacuum-tube voltmeter.

Attenuation Measurements

The attenuation of eoaxial eables is determined by measuring the ratio of sending-end to reeeiving-end voltage over a range of frequeneies.[1] The oscillator and eoupling unit are shown at the center in **Fig. 4.** A more eompaet oseillator and its power supply can be seen at the front in the seeond ease from the left.

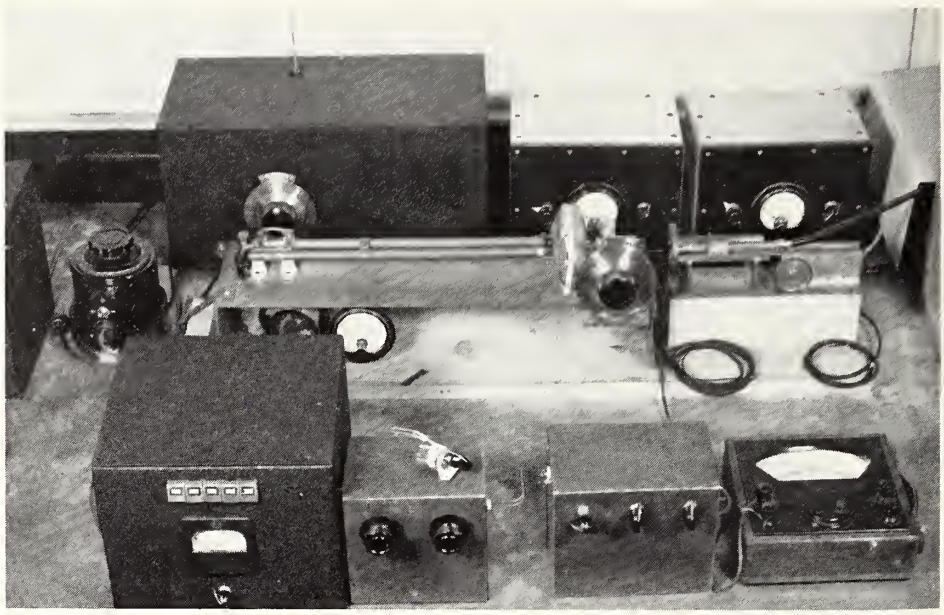


Fig. 4. Apparatus used to measure cable attenuation

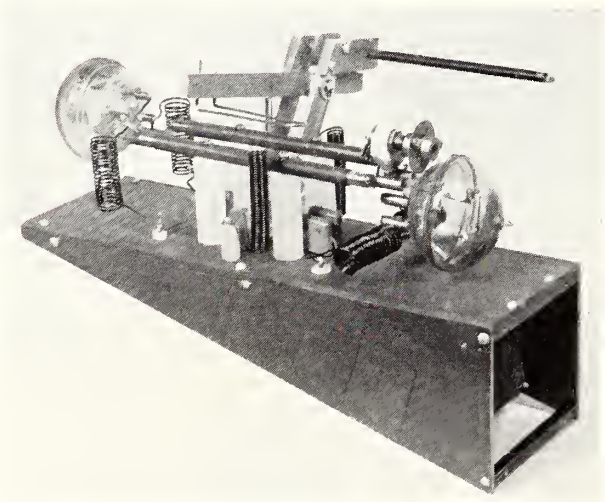


Fig. 5. The 300-megacycle oscillator with shielding case removed

The data sheet, shown in Table I, was set up to assist in taking the information neeessary to caleulate the dieleetrie constant, power factor, and loss faetor.

The power supply has a milliammeter on the front panel whieh ean be switched to indicate grid eurrent, plate eurrent, plate voltage, and heater voltage by means of the push buttons above the meter. **Fig. 5** shows this oseillator outside its shielding ease.

Conclusion

This installation of cable-testing faeilities now provides for the following:

(1). Measurement of surge impedanee at one kiloeyele and at one megaeyele.

(2). Measurement of power faetor and dielectrie eonstant of insulating materials over the frequency range of 42 to 70 megacyeles.

(3). Measurement of attenuation in coaxial cables over the frequency range of 300 to 325 megaeyeles.

Further expansion to include the measurement of attenuation in shielded twin-eonduetor eables is progressing.

(1)"Coaxial Cable Attenuation Measurements at 300 Megacycles," by Dr. H. H. Race and Dr. C. V. Larrick, GENERAL ELECTRIC REVIEW, vol. 44, p. 507, September 1941.

POWER FACTOR . . .

Dielectric power-factor measurements; and the progress that has been made in the development of improved measuring methods and equipment

By H. W. BOUSMAN
General Engineering Laboratory, General Electric Company

POWER dissipation in a dielectric subjected to alternating voltage is often a measure of the suitability of the dielectric material for a particular electrical insulation application.

Dielectric power factor is a parameter related to power dissipation and is characteristic of each material rather than dependent on the applied voltage and the shape of the specimen. There have been two ways of developing this concept. One is to consider the ratio of the power dissipated in a dielectric specimen to the product of the applied voltage and the current. By analogy to alternating-current power circuits, this ratio is called power factor. Power, voltage, and current are measured separately with appropriate instruments, conventional except that the wattmeter must be especially sensitive and free from phase error.

The other approach is based on measurement of the angle between vectors representing an applied voltage which varies sinusoidally with time and the consequent current through the dielectric assumed to vary in a similar fashion. If the current and voltage do vary in the fashion assumed, the cosine of the angular displacement between them is the power factor. Alternating-current measuring bridges have been developed to measure the cotangent of this angle, from which the cosine can be determined. In practice, measuring bridges are so arranged that if the waveforms encountered are not exactly sinusoidal, the relation between the fundamental components of the current and voltage waves is determined.

Dielectric design problems are encountered throughout the art of electrical engineering. This has led to a great variety of measuring means for dielectric power factor. It would be impossible to cover them all in the space available here but it may be interesting to trace the development of one particular branch of the art, that of measuring the power factor of high-voltage cable insulation.

Compensated Wattmeter Method

One of the early methods for cable-insulation power-factor measurement utilized the compensated dynamometer wattmeter.[1] Several features contributed to the success of this method.

(1). A sensitive dynamometer wattmeter was devised which was capable of a considerable deflection when measuring as little as 0.05 watts at 5000 volts.

(2). Shielding was used around the leads from specimen to wattmeter. This was a necessary precaution because the power dissipated in lead insulation was often of the same order of magnitude as that in the specimen. The shielding scheme was successful particularly because the wattmeter current-coil resistance was sufficiently low, in spite of the great sensitivity of the wattmeter, that current to the shields shunting the current coil was not of disturbing magnitude.

(3). A shielded and guarded air capacitor was built and shown to be free of dielectric loss up to 100 kv. Each measurement with the wattmeter was preceded by adjustment of the wattmeter potential-circuit phase angle to such a value that the wattmeter read zero power when connected to read the power loss in the air capacitor.

The compensated wattmeter method was capable of measuring power with sufficient accuracy to determine dielectric power factor within plus or minus 0.0002. It must be noted that because of difficulty in preparing a cable sample free from end effects, the measured power factor might fail to represent typical cable power factor exactly. Taking account of this difficulty, the accuracy of cable power-factor measurements was within plus or minus 0.0005. With the aid of this measuring tool, typical high-voltage paper-insulated-cable power factor was reduced from over 0.01 to about 0.003.

The next step in the dielectric power-factor measurement art was the construction of high-voltage measuring bridges. A Schering bridge was installed beside one of the compensated wattmeters in 1923. Its accuracy was the same but much operating and computing time was saved. Finally in 1933 the wattmeter was discarded.

Both methods were verified by calorimetric tests in 1927. Then, in 1930, thorough examination of the conditions affecting accuracy and sensitivity of the two methods was begun. Several principles to govern future development were determined:

(1). The shielded and guarded air capacitor was found to have been a sound development. With a little attention to mechanical detail, such a capac-

[1] "Compensated Dynamometer Wattmeter Method of Measuring Dielectric Energy Loss," by G. B. Shanklin, GENERAL ELECTRIC REVIEW, vol. 19, p. 842, Sept. 1916.

itor becomes a reliable impedance standard. With moderate care in design it is possible to assure stability of 0.01 per cent in capacitance and to 0.00001 or less in phase angle.

(2). The Schering bridge is capable of development to much greater sensitivity, thereby permitting measurement of smaller specimens at lower voltage.

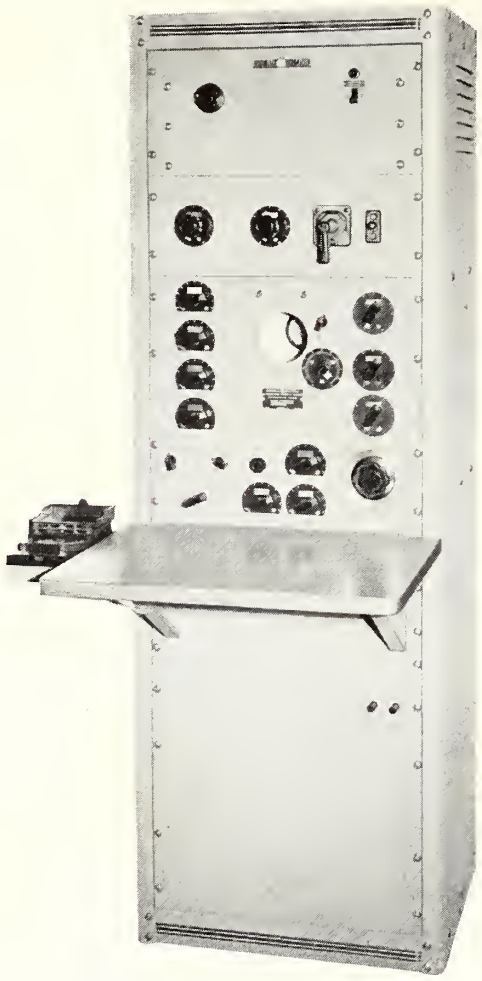


Fig. 1. A-c bridge designed for accurately and rapidly measuring dielectric power-factor and capacitance

(3). The Schering bridge galvanometer, which is connected between two corners of the bridge circuit, neither at exactly ground potential, must be isolated by shielding so that the admittance of all parts to ground is definitely fixed. A consequence of this requirement, for work of the highest accuracy, is that no external power supply for galvanometer excitation is allowable.

A-c Bridge Method

Further development, following these principles, led to a-c bridges capable of measuring very low loss dielectrics, such as new cable oils, to 0.00001 power factor. There is some reason to believe that, with certain precautions, the measurements are valid to one more decimal place and in fact several investigators have claimed accuracy to 0.000001 power factor. When speaking of accuracy of this order of magnitude, it is a bit awkward to keep count of the zeros past the decimal point, hence the term "microradian" for each 0.000001 radian less than 90 deg phase angle, which therefore makes 1 microradian equal to 0.000001 power factor.

When measuring small capacitances, such as cable-oil test cells, it is practicable to standardize the bridge by comparing standard air capacitors. Such comparisons may be extrapolated with assurance to standardize the bridge for measurements on 10-ft cable samples, but measurements on long lengths of cable require further verification. This has been accomplished by preparing four-terminal resistance standards of calculable phase angle. The bridge is standardized by comparing air capacitors, using in one bridge arm a 500-ohm or a 1000-ohm resistance which has had its phase angle calculated. Then a lower resistance four-terminal standard is substituted for the 500-ohm or 1000-ohm resistor when measuring large capacitances.

The over-all accuracy of this procedure was verified in 1940 by measuring the heat generated in a 0.32-mfd Pyranol capacitor at several 60-cycle voltages ranging from 16 kv to 20 kv. The power factor calculated from the calorimetric measurement agreed within 20 microradians with the power factor measured with a bridge in each case.

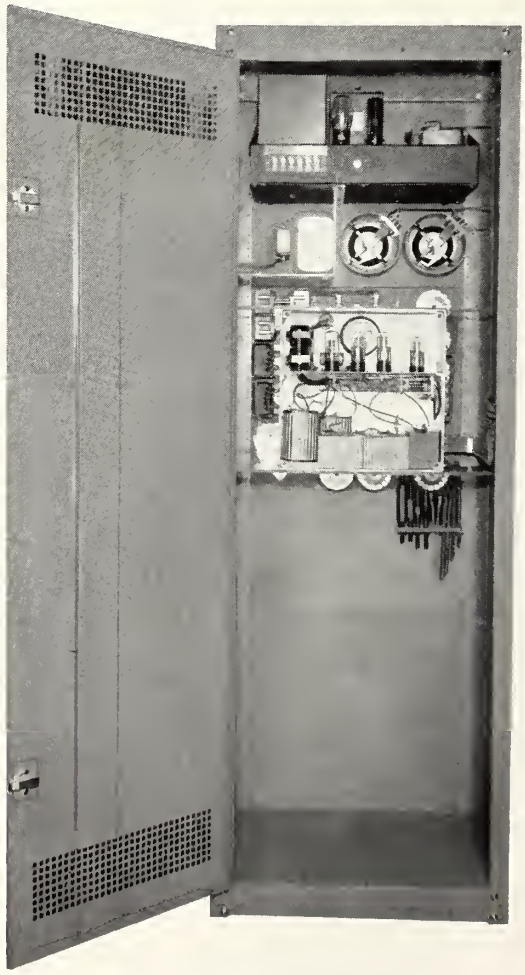


Fig. 2. Rear view of the a-c bridge shown in Fig. 1. From the top downward are located the voltmeter operated from capacitance voltage divider, the emergency control for power source, the bridge galvanometer amplifier, and the Ayrton shunt for long cable lengths

Incidental to the improvements in accuracy and sensitivity but of great importance for production testing are the improvements in convenience of manipulation. **Figs. 1** and **2** are front and back views respectively of a cable-testing bridge which was designed on the principles just set forth. This bridge is direct reading in 60-cycle power factor throughout its range, which is from one-half the capacitance of the standard air capacitor to 20,000 times this capacitance, a range of 40,000 to 1 in capacitance. There is a correspondingly wide range in the possible cable-charging current, a range which is accommodated by the Ayrton shunt in one bridge arm. Besides the bridge network itself, there are a voltmeter operated from a capacitance voltage divider of which the standard capacitor forms a part and an emergency control station for the power supply to the cables tested.

A typical standard air capacitor is shown in **Fig. 3**.

When a continuous record of the power factor is desired, use may be made of the alternating-current bridge shown in **Fig. 4**. This has proved most useful in connection with life tests on insulating materials tested to destruction. The bridge automatically adjusts itself to balance whenever any change occurs in the connected specimen and it maintains a continuous record of the power factor and capacitance change. The chart speed may be one inch per minute or one inch per hour. Choice of speeds is desirable in order to suit either short-time or long-time tests.

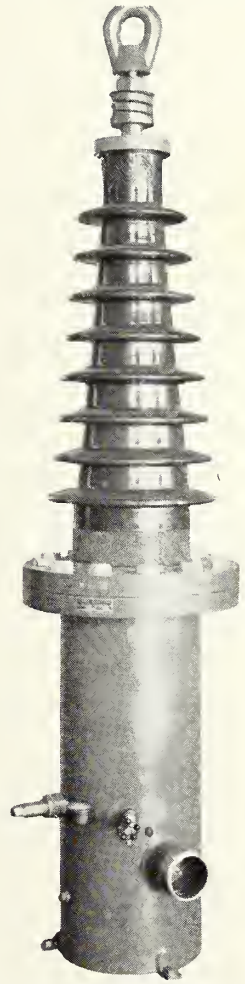


Fig. 3. A standard air capacitor, of 120-kv rating, such as is used in making the measurements

Fig. 4. Automatic recording a-c bridge, valuable in life tests of insulation

Summary

In summary, during a 25-year period there have been material improvements in the art of dielectric power-factor measurements on high-voltage cable and its components. The magnitudes of the improvement in accuracy, capacitance range, and sensitivity are indicated in Table I, in which the improvement is shown as the ratio of present performance to that in 1916.

TABLE I

Factor	TIMES IMPROVEMENT SINCE 1916	
	Complete Cable	Cable Components
Accuracy	5	100
Range	100	100
Sensitivity	10	100

SURGE TESTING . . .

In the field, in the laboratory, and in production to assure strength that will be adequate for transient as well as for normal conditions

C. M. Foust

By C. M. FOUST
General Engineering Laboratory, General Electric Company

HIGH-QUALITY performance of electric apparatus is achieved only by meeting service conditions fully. To do this, the designer incorporates adequate functional and strength features, and subsequent testing safeguards against imperfections in individual units. Experience has shown that it is not enough in either design or test to provide only for the normal voltages and currents necessary to the type of service required. Adequate strength features must be incorporated to safeguard against the electrical surge conditions that attend lightning, switching, short circuits, and other special transient conditions. A three-way attack on this problem, which has been progressing for some time, includes the following: (1) Field measurements of surge voltages and currents; (2) Laboratory surge investigations of apparatus and circuits; (3) Production surge tests of completed equipment.

(1). Field measurements of surge voltages and currents have been and are being made on power and industrial circuits, using special measurement equipment developed for the purpose—such as surge voltage recorders,[1] surge crest ammeters,[2] and cathode-ray oscillographs.[3]

For lightning surge voltages on power systems a crest value as high as 2800 kv[4] has been measured, and the flashover of the line insulation has been indicated as limiting the magnitude of these surges. Compared to normal circuit excitation, lightning surge-voltage crest values range up to twenty-times normal crest, with 50 per cent of all the surges being below 2.2 times normal.[5] Voltage steepness or rate of change of voltage at substation entrances has been recorded up to 545 kilovolts per microsecond.[6]

For switching-surge voltages on power and industrial circuits, crest values range up to 5.5 times normal, with 50 per cent of all surges reaching 2.2 times normal.[5]

For wave shapes of surge voltages and currents in the field, the cathode-ray oscillograph has been applied with success both for lightning and switching surges. Lightning surge-voltage wave fronts have been shown to range from 0.1 to 80 microseconds, and the time to half voltage value on the wave tail to range from 0.3 to 160 microseconds.[7]

(2). From laboratory surge investigations of apparatus and circuits is obtained direct experimental information on voltages, currents, and wave shapes throughout windings or circuits when subjected to waves that are selected as representing those measured in the field.

The elements in this surge mechanism are inductance, capacitance, and resistance magnitudes, and their distribution in the winding or circuit concerned. The surge mechanism varies widely, ranging from that typical of the transformer winding wherein potential and magnetic couplings between sections are high—resulting in a standing-wave impulse or oscillation—to that typical of rotating machinery where couplings between sections are low—resulting in a wave travelling down through the winding, with consequential reflections.

Depending upon the wave shape applied and the surge mechanism of the winding, internal voltage and current stresses will be distributed in characteristic manner. Turn-to-turn, layer-to-layer, and conductor-to-ground insulation stresses critical to continued apparatus performance are evaluated in terms of waves that represent those recorded by field measurements. This surge mechanism can be determined with a surge generator and cathode-ray oscillograph but is done with much greater speed and accuracy with the electric transient analyzer[8] of the oscillographic type shown in **Fig. 1**.

(3). High-voltage surge testing with single surge applications is increasingly regarded as assurance against insulation failure caused by power-circuit surges.[9] In this field, voltages of prescribed shape ranging up to 2000 kv have been extensively utilized.

(1)"Instruments for Lightning Measurements," by C. M. Foust, GENERAL ELECTRIC REVIEW, vol. 34, p. 235, April 1931.
(2)"Direct Measurement of Surge Currents," by C. M. Foust and J. T. Henderson, *Electrical Engineering*, vol. 54, p. 373, April 1935.
(3)"Some Recent Developments in Impulse Voltage Testing," by C. M. Foust and N. Rohats, *Electrical Engineering*, vol. 59, p. 257, May 1940.
(4)"Lightning Investigation on the 220-kv System of the Pennsylvania Power and Light Company: 1930," by Edgar Bell and A. L. Price, *Transactions A.I.E.E.*, vol. 50, 1931.
(5)"Lightning Investigations on Transmission Lines: II," by W. W. Lewis and C. M. Foust, *Transactions A.I.E.E.*, vol. 50, 1931.
(6)"Lightning Investigations on 132-kv Transmission System of American Gas and Electric Company," by I. W. Gross and G. D. Lippert, *Transactions A.I.E.E.*, vol. 61, 1942.
(7)Lightning Investigation on Transmission Lines: IV," by W. W. Lewis and C. M. Foust, *Transactions A.I.E.E.*, vol. 53, 1934.
(8)"A New Instrument for Analyzing Electric Transients," by N. Rohats, GENERAL ELECTRIC REVIEW, vol. 45, p. 121, Feb. 1942.
(9)"Impulse Testing Technique," by C. M. Foust, H. P. Kuehni, and N. Rohats, GENERAL ELECTRIC REVIEW, vol. 35, p. 358, July 1932.

Recently accumulated data have shown that adequate volt-time breakdown information can be obtained only when close adherence to the prescribed wave is maintained. Consequently, in laboratory and factory tests, progress has been made in wave-shape control and measurement. This has been accomplished through more compact discharge circuits of lower inductance and the addition of circuit-loading elements of predetermined capacitance, inductance, and resistance values. The predetermination of circuit-loading elements is accomplished rapidly and accurately by setting up a miniature and easily adjusted discharge circuit on the oscillograph electric transient analyzer. With the required circuit constants available, the high-voltage discharge circuit is set up without the numerous delays that attend the old trial-and-error method of circuit adjustment.[3]

A marked simplification and speed-up in surge testing are accomplished through the substitution of the sealed-in high-voltage high-vacuum cathode-ray oscillograph[3] shown in **Fig. 2** for the commonly used cold-cathode internal-photography instrument. Experience has shown that a very substantial saving in time results when the vacuum pumps necessary to the internal photography oscillograph are no longer required. Delays and uncertainties involved in repeatedly breaking the vacuum chamber, pumping down, and making the vacuum adjustment, are all eliminated. In addition, the use of the outside camera focused on the fluorescent screen of the oscillograph tube, inside a darkened chamber, provides for simultaneous visual observation and photographic recording of every wave shape applied to the oscillograph deflection plates.

Fig. 1. The oscillographic type of electric transient analyzer that facilitates the determination of surge mechanisms when making surge investigations in the laboratory

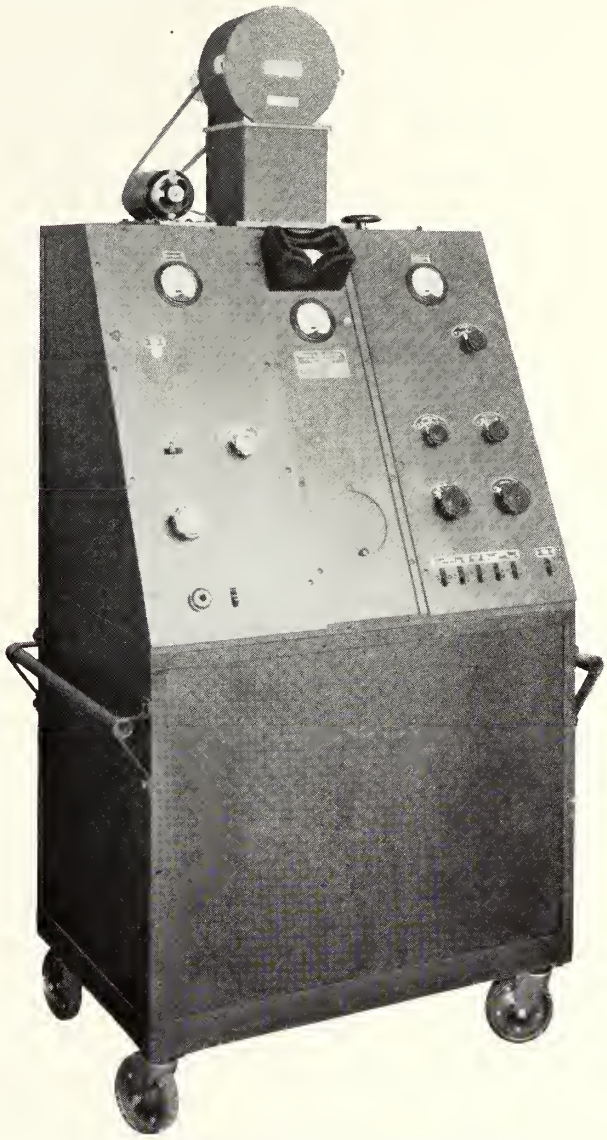


Fig. 2. The high-speed sealed-in hot-cathode cathode-ray oscillograph that was developed to record the shape of waves of very short duration

The question of writing speed of this type oscillograph is one that has been given much attention. Before adapting this oscillograph to surge testing it was determined, through many tests, that the special high-voltage tube design provided more than adequate writing speed for the standard (1×5) and ($1\frac{1}{2}\times40$) microsecond waves. Since that time the writing speed has been further improved through advances in high-speed camera lenses and improvements in screen material.

An illustration of volt-time curves, a type of data most common to surge testing, is reproduced in **Fig. 3** to show how the complete data for such a curve, including time and amplitude calibrations, are compactly recorded without overlapping of

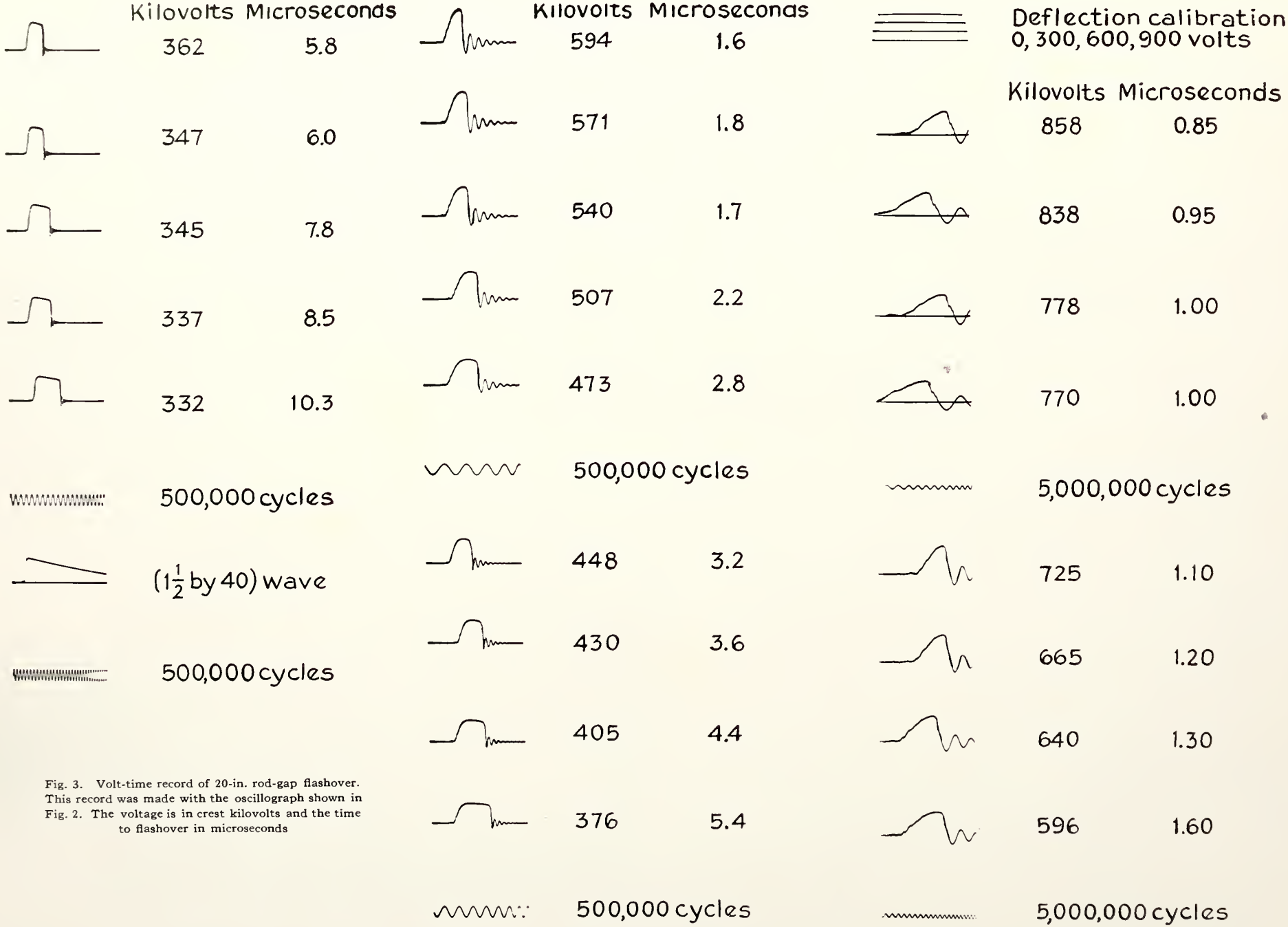


Fig. 3. Volt-time record of 20-in. rod-gap flashover. This record was made with the oscillograph shown in Fig. 2. The voltage is in crest kilovolts and the time to flashover in microseconds

records. Each recorded wave and calibration was observed visually as it was photographed, thus eliminating the necessity of returning later for flashover records that were missed.

In **Fig. 3** the progress of the test reads up the left column, then up the center, and then up the right. A calibration of the time axis with a 500,000-cycle wave begins at the bottom of the left column. Immediately above it is the ($1\frac{1}{2}\times40$) microsecond testing wave showing the long persisting tail. To measure time accurately on the flashover of the rod gap, the time-axis speed was increased and another 500,000-cycle calibration wave taken. The fourth wave up on the left shows critical flashover of the rod gap at 332 kv and 10.3 microseconds. Thereafter, the voltage amplitude was raised in steps resulting in correspondingly decreasing time to flashover.

Going up from the bottom of the center column the speed of the time axis was again increased, followed by a flashover at 376 kv and 5.4 microseconds. This method continued up through the column to a flashover of 594 kv and 1.6 microseconds. At the bottom of the right column the time-axis speed was still further increased and calibrated with a 5×10^6-cycle timing wave. Continuing upward to the last flashover oscillogram near the top of the column, it will be seen that flashover occurred at 858 kv and 0.85 microseconds. The total time axis is 2 microseconds for this record and the writing speed at the fluorescent screen is 1.5 meters per microsecond. Records requiring 5 meters per microsecond have been satisfactorily obtained. This, on the basis of a readily measurable deflection of 10 cm on the oscillograph screen, provides for short-time measurements ranging below 0.01 microsecond.

Progress in cold-cathode internal-photography cathode-ray oscillography has been recently described.[10] This oscillograph should be regarded as a precision research tool capable of recording ultra-fast phenomena. Due to complexity of circuits, the operator must use considerable care and skill to realize the best performance. The recent improvements mark definite progress in high-speed recording and add definitely to performance characteristics hitherto attained. The availability of this ultra-fast oscillograph, along with the general-purpose instrument that has been briefly described in the foregoing, provides adequately for the full range of service use.

Summarizing briefly with regard to instruments for surge testing, the surge voltage recorder for voltage crests and the surge crest ammeter for current crests are appropriate for field measurements; the electric transient analyzer provides for circuit or apparatus surge analysis in a direct and convenient manner; and the sealed-in hot-cathode-ray oscillograph marks a decided advance in complete wave shape recording of electrical phenomenon of short-time duration.

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[10] "Modern Cathode-ray Oscillograph for Testing Lightning Arresters," by E. J. Wade, T. J. Carpenter, and D. D. MacCarthy, A.I.E.E. 1942 Summer Convention, Paper 42-108.

MAGNETIC MEASUREMENTS . . .

A. E. Kettner

Made with core-loss testers, permeameters of the precision, full-range, saturation, isthmus, and other types; hysteresigraph, and special high-temperature testing equipment

By A. E. KETTNER
General Engineering Laboratory, General Electric Company

THREE basic types of materials are used in the products of the electrical industry—magnetic materials, electrical conductors, and electrical insulators. As complete and accurate information as possible on the magnetic properties of the magnetic materials and structures used is essential for the greatest success in both electrical manufacturing and research.

To provide this necessary information, the modern magnetics laboratory must be equipped to measure the useful magnetic properties of any given material, to find material best suited for a given purpose, and to aid in developing new and better materials through study of test results.

In accomplishing these aims, the importance of accuracy, of speed, and of simplicity in the test methods used, assumes different proportions according to the type of work which is being done. For research, where accurate fundamental data are sought, relatively laborious and complicated methods are often justified. On the other hand, in routine acceptance tests, where a large number of tests are made each day, speed and reproducibility are essential and in general less accuracy is required.

Magnetic Properties

The principal magnetic properties commonly required include the following measurements:

(1). Core loss
  (a) Hysteresis loss; (b) Eddy-current loss
(2). Normal induction
(3). Saturation
  Maximum intrinsic induction
(4). Hysteresis loops
  (a) Symmetrical; (b) Unsymmetrical
(5). Magnetic permeability of feebly magnetic materials
(6). Magnetization vs. various temperatures
(7). Magnetostriction[1]
(8). Aging of magnetic materials.

Magnetic Materials

Aside from materials tested for special research work, magnetic materials for commercial applications may be considered under the following five classifications: (1) Solid-core materials for relay and solenoid applications, and magnetic materials used primarily for structural and mechanical purposes but also required to form part of a magnetic circuit; (2) electrical sheet and strip for laminated cores; (3) permanent magnet alloys; (4) special-purpose alloys having either thermomagnetic properties (sometimes referred to as temperature-sensitive alloys) or high permeability at low inductions, high saturation, constant permeability, or other special properties; and (5) feebly magnetic materials commonly referred to as nonmagnetic steels.

In addition to testing magnetic materials after heat treating or annealing, it is necessary to determine the effect of aging treatments on the permeability and hysteresis of the various materials, particularly those used in meters, relays, and machines. It is also important to investigate the effect of magnetic and metallurgical aging in the development of new alloys.

The relations of flux density to magnetizing force for a large number of important magnetic materials is shown in **Fig. 1.**

Magnetic Testing Equipment

With the increased activity in the development of new and superior magnetic materials during the past fifteen years, there has also been considerable activity in the development and improvement of the necessary testing equipment.

The present standard equipment for measuring the core loss of sheet or strip material is based on the Epstein method, in accordance with the specifications of the American Society for Testing Materials.[2] The specimen consists of 10 kg of test material cut into strips 50 cm by 3 cm. The standard tests are made at maximum inductions of 10,000 and 15,000 gausses and a frequency of 60 cycles per second. When it is desired to separate the hysteresis and eddy-current losses at a given induction, tests are made at several frequencies, usually 30, 40, 50, and 60 cycles per second.

A method that utilizes less material and is more convenient for factory routine inspection has been developed for measuring the core loss of 25-cm by

(1)"Magnetostriction Phenomena," by W. D. Williams, GENERAL ELECTRIC REVIEW, vol. 45, p. 161, March 1942.

(2)"Standard Methods of Test for Magnetic Properties of Iron and Steel," *American Society for Testing Materials*, Serial designation: A34-42.

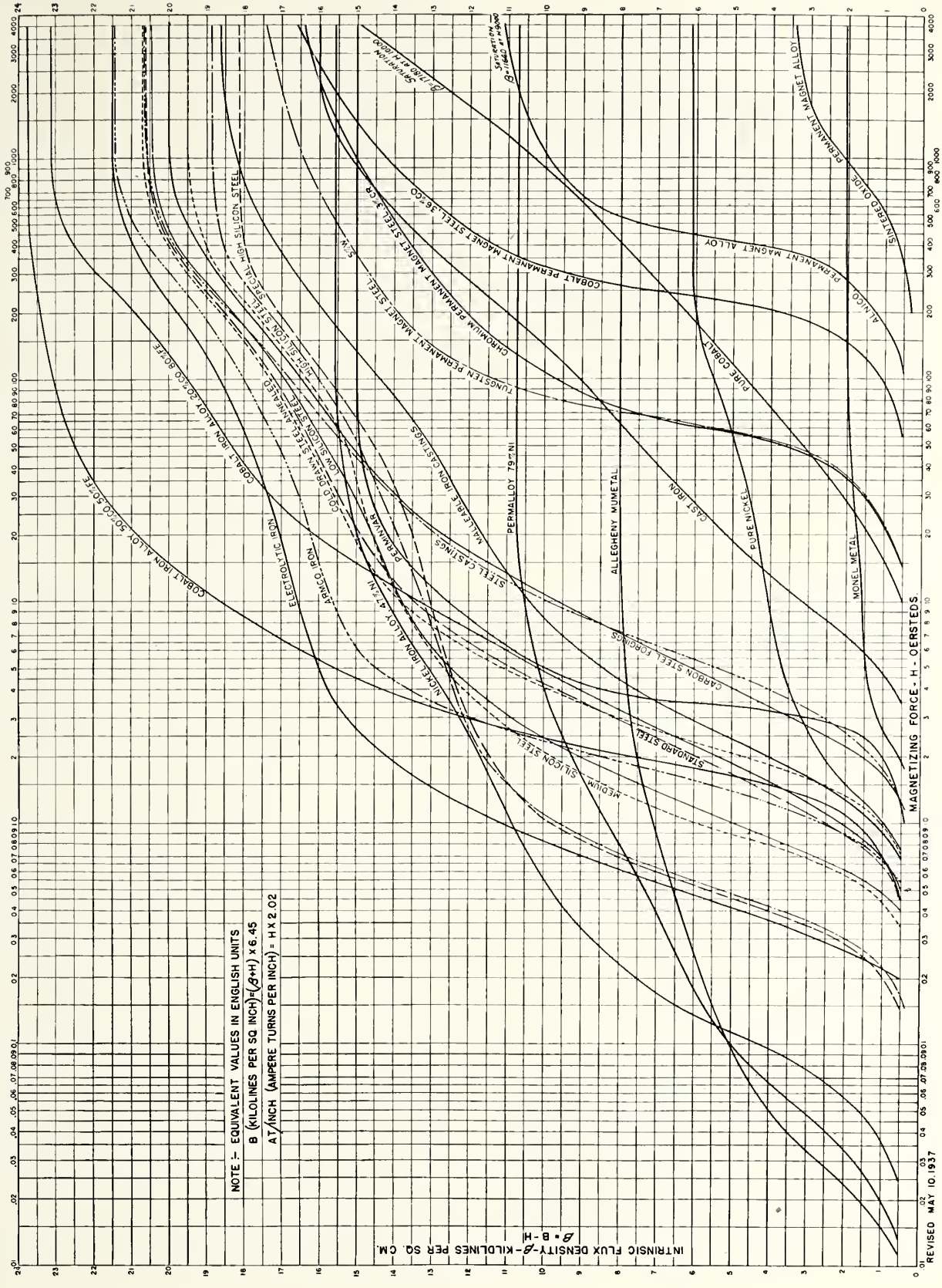
MAGNETIZING FORCE - H - OERSTEDS
INTRINSIC FLUX DENSITY - $\mathcal{B}$ - KILOLINES PER SQ. CM.
$\mathcal{B} = B - H$
NOTE :- EQUIVALENT VALUES IN ENGLISH UNITS
B (KILOLINES PER SQ INCH) = $(\mathcal{B}+H) \times 6.45$
AT/INCH (AMPERE TURNS PER INCH) = H X 2.02
REVISED MAY 10, 1937
COBALT PERMANENT MAGNET ALLOY
PERMANENT MAGNET ALLOY
SINTERED OXIDE
ALNICO
PURE COBALT
CHROMIUM PERMANENT MAGNET STEEL
TUNGSTEN PERMANENT MAGNET STEEL
ALLEGHENY NUMETAL
CAST IRON
PURE NICKEL
MONEL METAL
MALLEABLE IRON CASTINGS
STEEL CASTINGS
PERMALLOY 79% NI
ARMCO IRON
ELECTROLYTIC IRON
NICKEL IRON ALLOY 47% NI
CARBON STEEL FORGINGS
STANDARD STEEL
MEDIUM SILICON STEEL
HIGH SILICON STEEL
COBALT IRON ALLOY 50% CO 50% IRON
COBALT IRON ALLOY 65% CO 35% IRON

Fig. 1. D-c magnetization curves for various typical magnetic materials

3-cm (1.25-kg) specimens. The equipment shown in **Fig. 2** is based on a modification of the Epstein method with the least possible departure from the standard test procedure. The measurements are normally made at inductions of 10,000, 12,500, and 15,000 gausses at a frequency of 60 cycles per second. The range can be extended to cover inductions of 200 to 19,000 gausses[3] and frequencies of 25 to 2000 cycles.

To determine the comparative effects of the various manufacturing processes and treatments of electrical

[3] "Measuring Core Loss at High Densities," by B. M. Smith and C. Concordia, *Electrical Engineering*, vol. 51, p. 36, January 1932.

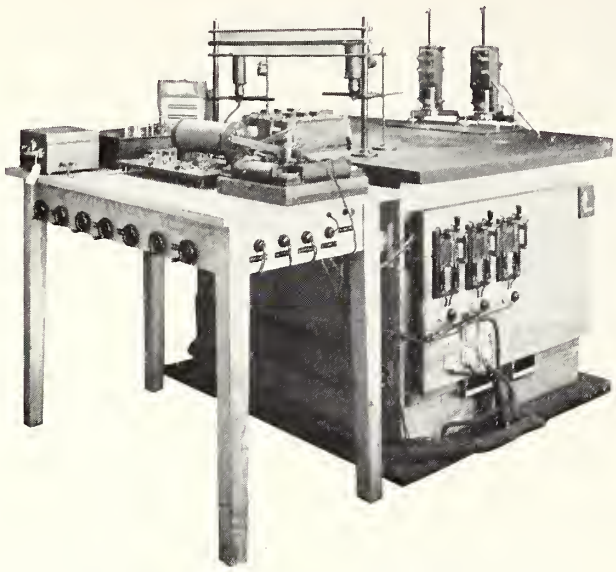

Fig. 2. Equipment for making routine core-loss tests on 1.25-kg samples of sheet steel

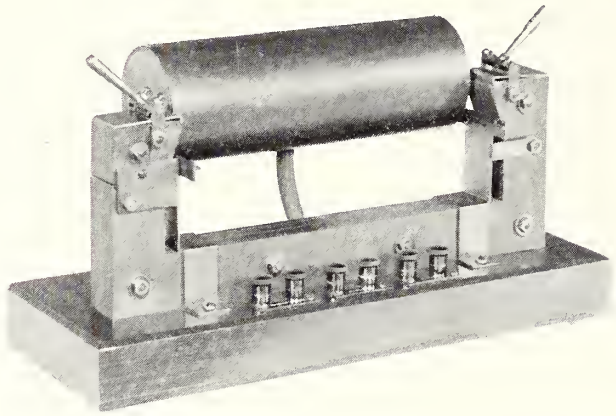

Fig. 3. The core loss of a single strip, 25 cm by 3 cm, can be determined with the aid of this tester designed for the purpose

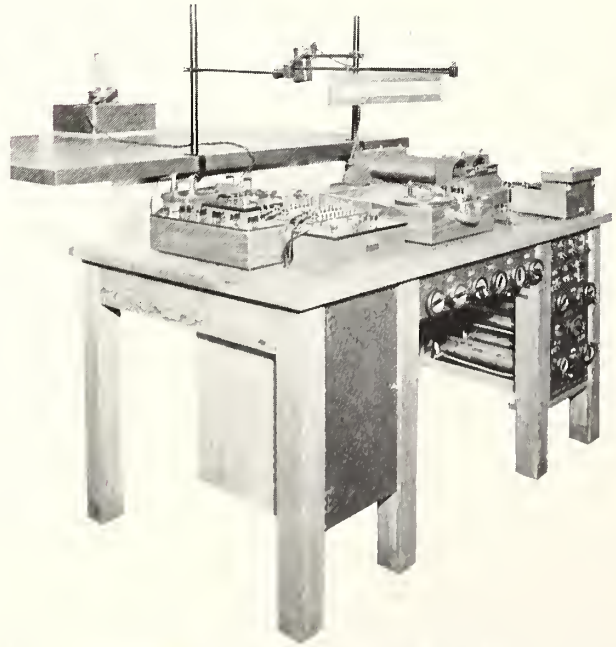

Fig. 4. Permeability and hysteresis testing equipment for precise measurements on materials including high permeability alloys

sheet and strip steels, it is often desirable to determine the core loss in a small section of the material. A tester to accommodate a single specimen 25 by 3 cm by 10 to 50 mils thick was developed,[4] and is shown in **Fig. 3.** This tester was designed for the measurement of 60-cycle core loss at inductions ranging from 8000 to 15,000 gausses. By its use, considerable progress has been made in the development of sheet and strip materials.

A number of equipments have been developed for measuring the d-c normal induction and the hysteresis of either sheet or solid magnetic materials. Among these are a full-range permeameter and a precision permeameter.

The full-range permeameter[5] is a compensated single-yoke instrument which was designed for the rapid testing of commercial specimens. The normal range of test is from H = 0.01 to H = 1000 oersteds but higher magnetizing forces up to 1400 oersteds can be attained for short periods. The permeameter requires only one test piece and will accommodate specimens up to $1\frac{3}{16}$ in. in width by $\frac{1}{2}$ in. in thickness and of any length not less than 10 in.

For precise measurements on materials including high-permeability alloys, the precision permeameter equipment shown in **Fig. 4** was developed. The permeameter employs a compensated double-yoke with several magnetizing windings and requires two specimens of the material to be tested. It is designed to cover a range of magnetizing forces extending from H = 0.005 to H = 300 oersteds. The specimens to be tested are preferably 3 cm by 0.7 cm in cross section and 50 cm long. A permeameter for specimens 25 cm has also been constructed for use with this equipment.

A saturation permeameter[6] of the bar-yoke type was developed for the accurate measurement of the saturation, or maximum intrinsic induction, of materials which are saturated within the working range of the permeameter. It was later adapted for hysteresis measurements on permanent-magnet materials where high values of the magnetizing force are necessary. Its range of test extends from H = 100 to H = 4000 oersteds for saturation tests and to 2500 oersteds for hysteresis measurements. Tests may be extended to 3000 oersteds for determining the demagnetization curve of permanent-magnet materials. The permeameter has been designed to accommodate either strip specimens 3 cm by 0.7 cm in cross section or bar specimens 1.59 cm square and 25 cm long.

The hysteresigraph, shown in **Fig. 5**, is a recent development for recording graphically the initial magnetization curves or any desired symmetrical or unsymmetrical hysteresis loops of permanent magnet and other magnetic materials. It is a d-c instrument which can be used to test either laminated or solid

(4) "A Tester for Measuring Core Loss of Single Strips," by T. G. Smith, GENERAL ELECTRIC REVIEW, vol. 40, p. 273, June 1937.
(5) "A New Full-range Permeameter," by B. M. Smith, GENERAL ELECTRIC REVIEW, vol 38, p. 520, November 1935.
(6) "Saturation Permeameter," by S. L. Gokhale, *Journal A.I.E.E.*, vol. 47, p. 196, March 1928.

specimens in ring or bar form. For bar specimens, it can be used in conjunction with any permeameter which does not require compensation for joint reluctance. It is frequently used with the saturation permeameter to determine the hysteresis characteristics of permanent magnet materials.[7]

Permeameters of the isthmus electromagnet type[8] provide the highest magnetizing force and are the best suited for short test specimens. The electromagnet shown in **Fig. 6** is designed for producing intense magnetic fields with maximum efficiency and minimum weight. It is used for measuring the saturation induction and hysteresis characteristics of magnetic materials by the well-known isthmus method and for other investigations requiring high magnetic intensities. This particular design is capable of supplying magnetizing forces up to 2700 oersteds depending on the size of the polar surfaces, the gap between poles, and the magnetizing current.

Measurements to determine the magnetic permeability of feebly magnetic materials are made with a permeameter[2] employing a single solenoid without yokes as shown in **Fig. 7**. Materials of this classification have a permeability slightly greater than unity but do not exceed two in maximum permeability. The measurements of induction are usually made with magnetizing forces extending from 5 to 500 oersteds. For tests with this particular permeameter, the specimens should be at least 10 cm long and not more than 1.9 cm in diameter.

For the testing of thermomagnetic alloys, and the determination of the Curie region of magnetic materials, special equipment has been developed for measuring the induction and the remanence at various temperatures. The equipment essentially consists of a special magnetizing solenoid and test coils built to withstand high temperatures. The testing range of this equipment includes magnetizing forces up to 500 oersteds and temperatures extending from 25 C to 1000 C. The tests are usually made on bar specimens at least 4 cm long and not exceeding 1.27 cm square in cross section.

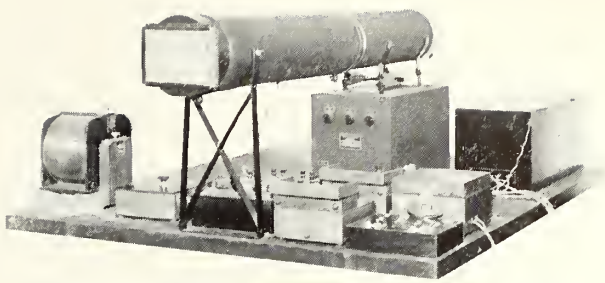

Fig. 5. Photoelectric hysteresigraph for recording magnetization curves and hysteresis loops

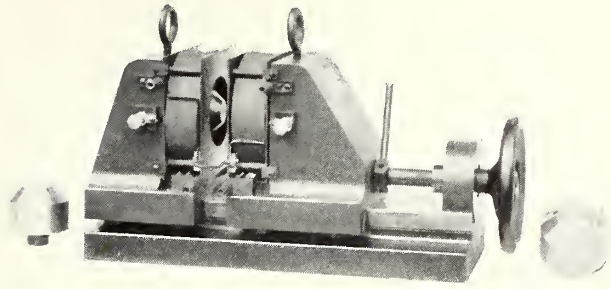

Fig. 6. Isthmus electromagnet for measuring magnetic characteristics at high intensities, using short test specimens

Fig. 7. Permeameter for testing feebly magnetic materials

Summary

The value of magnetic measurements has become more important with the rapid development of new and improved materials, methods of manufacture, and application of these materials to the design of more economical and efficient electrical apparatus. These measurements require the use of a wide variety of special testing facilities to determine the properties and characteristics of the different classes of magnetic materials. With such facilities in the laboratory, the maintenance of magnetic standards of measurement of induction, magnetizing force, and core loss is made possible.

The standardization of measurements on the various equipments can be made on carefully selected and prepared test specimens. These magnetic standards can then be compared with those of the National Bureau of Standards[9] and can be checked through round-robin tests conducted by the American Society for Testing Materials. The measurements necessary for commercial testing are made in accordance with the specifications of the A.S.T.M. Standard Methods of Test for Magnetic Properties of Iron and Steel.[2]

(7) "A New Photoelectric Hysteresigraph," by R. F. Edgar, *Electrical Engineering*, vol. 56, p. 805, July 1937.

(8) "Alnico—Properties and Equipment for Magnetization and Test," by B. M. Smith, GENERAL ELECTRIC REVIEW, vol. 45, p. 210, April 1942.

(9) "Magnetic Testing," by R. L. Sanford, *U. S. Department of Commerce—National Bureau of Standards*. Circular C415.

MAGNETOSTRICTION MADE VISIBLE

Stephen C. Leonard

Rapid magnetostriction measurements to a fraction of a millionth of an inch made a routine procedure

By S. C. LEONARD
Pittsfield Works Laboratory, General Electric Company

THE diseovery that magnetie materials change their physieal dimensions under the influenee of a magnetie field dates baek to the middle of the last eentury. So many artieles have been published on the subject of magnetostrietion phenomena during the period from 1847 to 1927 that the interested researeher ean accumulate a creditable library on the subjeet with little effort.(1)

With the exeeption of the invention of the magnetostriction oseillator,(2) the average engineer gave little thought to the minute physical changes associated with magnetostrietion until industry beeame noise eonseious about ten years ago. At that time, it was found that small eontinuous noise, sueh as the hum of a transformer core or a refrigerator motor, irritated some human nervous systems. This sometimes redueed the efficieney of the persons affeeted to a marked degree. Many offiee buildings were soundproofed and attempts were made to reduce the sound of all maehinery used in eongested city and suburban distriets. The sound-level meter(3) was developed and audible sound beeame a factor in the design of some types of apparatus. The designer of induetion apparatus beeame aware of the possible relationship between magnetostrietion in eore material and the audio sound of iron-core apparatus. Today, the electrical design engineer is beginning to request magnetostriction data on many types of core material so that he ean intelligently design quieter eleetrieal apparatus.

To keep paee, the metallurgist requires speeial measuring equipment to furnish these data and to insure the development of quieter core material in the future. The instrument development engineer, in turn, is faced with the problem of produeing an instrument that will measure ehanges in length in the order of a millionth of an inch per ineh as readily as a voltmeter measures diffcrences in eleetrie potentials.

General Design Problems

The problem of developing equipment suitable for obtaining routine design data on a large number of samples of transformer eore material is entirely different from the measurement problem of the research physicist interested in the purely theoretieal aspeets of magnetostriction phenomena. Equipment to be used for routine and control testing has to be sturdy and simple to operate. The main problems may be listed as follows:

(1) Elimination of critieal adjustments and ealibrations
(2) Automatie temperature eompensation
(3) Simple arrangement for ehanging test samples
(4) Direct indication of magnetostrietion in millionths of an ineh per ineh.

Methods of Measurement

To simplify the design problem, it was deeided to use d-e exeitation and limit the equipment to a measurement of the ehange in length of a sample in the direction of the applied magnetie field. This is the so-ealled Joule effect, the most prominent of all the magnetostrietion effects and presumably the most indieative of audio sound in eores of induction apparatus.

Three basie methods have been used by experimenters in the past for making this type of measurement: (1) meehanieal, (2) eleetrieal, (3) optieal or visual.

Meehanical methods(4) did not appear adaptable to faetory use since an effeetive meehanical-lever-arm ratio of a million-to-one would be required. Sueh a lever system is extremely critieal to adjust and ealibrate and subjeet to large errors from frietion and vibration.

Of the electrical methods the one based on the measurement of the ehange in capaeitanee in a tank eireuit of a high-frequency oscillator seemed the most praetical.(5) Sueh a method, however, was considered to require too mueh technieal skill on the part of the

(1) "A Review of Magnetostriction," by L. W. McKeehan, *Journ. Frank. Inst.*, vol. 202, p. 737, 1926.
"Some Experimental Methods in Magnetostriction," by S. R. Williams, *J.O.S.A. & R.S.I.*, May 1927
"Magnetostriction Phenomena," by W. D. Williams, GENERAL ELECTRIC REVIEW, vol. 45, p. 161, March 1942.
(2) "Magnetostriction Oscillators," by G. W. Pierce, *Proc. IRE.*, p. 42, January 1929.
(3) "A New Sound Level Meter," by A. J. Muchow, GENERAL ELECTRIC REVIEW, vol. 39, p. 293, June 1936.
"A Portable Frequency Analyzer," by M. S. Mead, Jr., and T. M. Berry, GENERAL ELECTRIC REVIEW, vol. 37, p. 378, August 1934.
"An Improved Sound Level Meter," by W. Mikelson, GENERAL ELECTRIC REVIEW, vol. 43, p. 515, December 1940.

(4) "The Magnetostriction of Single Crystals of Iron," by Kotaro Honda and Yoshio Mashiyama, *Sci. Refs.* Tohoku Imp. Univ., p. 755, 1926.
Austin and Guthe, Bulletin, Bureau of Standards, p. 297, 1906.
S. R. Williams, *Physical Review*, p. 258, 1912, and *J.O.S.A.*, vol. 7, p. 1011, 1923.
(5) "The Effect of Tensile on Magnetostriction of Steel," by J. S. Rankin, *Glasgow Roy. Tech. Coll. Journ.*, vol. 2, p. 273, 1929–32.

operator, in addition to requiring too costly auxiliary equipment.[6]

The optical or visual method[7] based on the interference of light appeared to be the most practical. In this case, each measurement is referred directly to a basic standard, the wavelength of sodium light. This automatically eliminates the calibration problem and errors inherent in attempting to obtain an extremely high magnification by mechanical means alone.

Factory Application of Visual Method

Instead of using a Michelson inferometer[8] which is somewhat critical to adjust, A. W. Everest, a co-worker and widely known amateur astronomer and telescope maker,[9] proposed the use of a balanced lever arm with two optical flats to replace the Michelson inferometer as an indicating device. It was demonstrated that such a device was simple to operate, could be made direct reading, and could be compensated for temperature errors.

Optical-measurement Lever Arm

The schematic arrangement of the optical lever arm is shown in **Fig. 1(*a*)**. If the point P is considered fixed in relation to the lever fulcrum, F, it will be seen that any change in length of the sample under test will change the spacing between the two optical flats in direct proportion to the lever-arm ratio, B/A. As shown in **Fig. 2(*a*)**, sodium light projected normal to the flats produces an interference pattern dependent upon the spacing between the flats.[8] Thus, change in spacing between the two flats is measured directly in terms of wavelength of light by simply counting the number of interference lines that appear to pass the reference index as the sample is magnetized.

The optical flats are Pyrex disks with the inner measuring surfaces polished flat to ± 0.000004 in. The bottom surface of the lower flat is ground and painted black to eliminate light reflection. Reflections from the top surface of the upper flat are deflected away from the field of vision by a small glass wedge. Since the sodium-arc spectrum has two bright lines, one at 5890 angstroms and one at 5896 angstroms (both yellow), the interference pattern appears as a series of alternate black and yellow lines. A movement of one light and one dark band across the reference index represents a change in spacing at this particular point of one-half wavelength of sodium light, or 11.6 millionths of an inch based on the average value of 5893 angstroms.[8] By making the optical-lever-arm ratio (B/A) equal to 11.6-to-1, we have a direct-reading scale of magnetostriction of one millionth of an inch per division (one dark and one light line). By a slight adjustment of the tilt between the two flats the interference bands can be expanded so that one millionth of an inch is readily magnified to a visual-scale reading of one-half inch, an over-all magnification of 500,000-to-1 with a mechanical magnification of only 11.6-to-1.

Temperature-compensation Arm

Unfortunately, the temperature coefficient of steel is such that the temperature effect is of the same order of magnitude as the magnetostriction effect. Thus, any heat dissipated by the magnetizing coil or abrupt changes in the ambient temperature directly effect the accuracy of measurement.

To eliminate these effects, the temperature compensation arm, shown in **Fig. 1(*b*)**, was incorporated in the design. Instead of making the sample support,

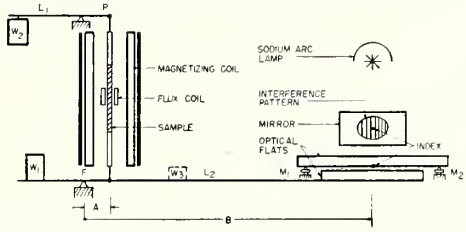

Fig. 1(*a*). Schematic arrangement of the optical-measurement lever arm

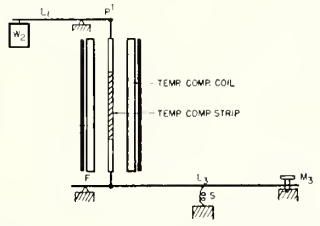

Fig. 1(*b*). Schematic arrangement of temperature-compensation lever arm

P, fixed, it is tied back through P' to the main supporting frame by means of the temperature-compensating strip. The sample and compensating-strip support points, P and P', are both attached to the upper compensating lever, L_1. This lever is common to both the measurement and compensating arms as shown in **Figs. 1** and **2**. Since the lower adjustment arm, L_3, is firmly fastened to the main supporting frame by a heavy hold-down spring, S, any elongation or contraction of the compensating strip caused by temperature changes allows the support points, P and P', to rise and fall slightly to compensate for similar changes in the sample under test. The magnetizing and temperature-compensating coils are physically identical, being long solenoids of dual-strand windings. The two coils are connected in series, the windings of the former being connected "aiding" to magnetize the sample, and the latter connected "bucking" to eliminate the field around the compensating strip. Since the same value of current flows through both coils and since duplicate specimens of

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(6) "Measurement of Minute Changes of Capacitance and Inductance," by S. C. Leonard, *Electronics*, p. 18, March 1938.

(7) "Some Experimental Methods in Magnetostriction," by S. R. Williams, *J.O.S.A. and R.S.I.*, p. 386, (Fig. 1), May 1927.
"Magnetostriction Effects," by S. R. Williams, *Physical Review*, vol. 4, p. 501, 1941.

(8) Hardy & Perrin, *The Principles of Optics*, p. 568–594, McGraw Hill, 1932.
Weld and Palmer, *Textbook of Modern Physics*, p. 685–687, Blakiston, 1925.

(9) "*Amateur Telescope Making Advanced*," pp. 3–48, *Scientific American*, 1937.

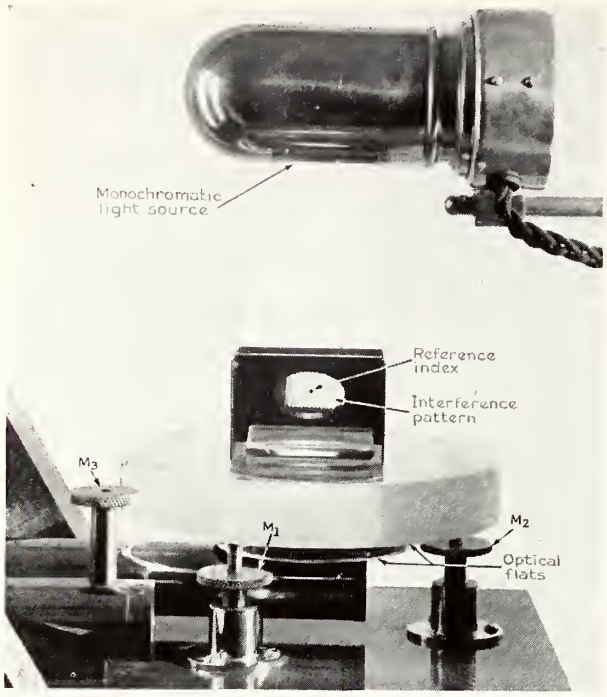


Fig. 2(*a*). The optical-system assembly of the magnetostriction test equipment

steel are used for the test sample and compensating strip, excellent temperature compensation is obtained by this method.

To minimize extraneous temperature errors the main supporting framework is made of wood to insure slow heat absorption. All lever arms are made of brass tubing for rigidity and chromium plated to reflect heat. The fulcrum points of all lever arms are hardened-steel knife edges with self-aligning agate bearings as used in any precision balance.

Lever-arm Adjustments

The tilt of the upper optical flat is adjusted by means of the two micro thumb screws, M_1 and M_2 shown in **Figs. 1(*a*)** and **2(*b*)**. These adjustments control the width and tilt of the individual interference bands. The initial spacing between the flats after the sample and compensating strips are hung in place is adjusted by means of the micro thumb screw M_3 shown in **Figs. 1(*b*)** and **2(*b*)**. These adjustments are not critical and can readily be made by an unskilled operator. The mass, W_2, on the lever, L_1, puts a large tension on the compensating strip and assures perfect behavior of the compensating lever. The mass W_1 counterbalances the mass of the lower optical flat, while W_3 represents different values of tension loads that may be applied to the sample under test to obtain magnetostriction data vs. tensile stress.

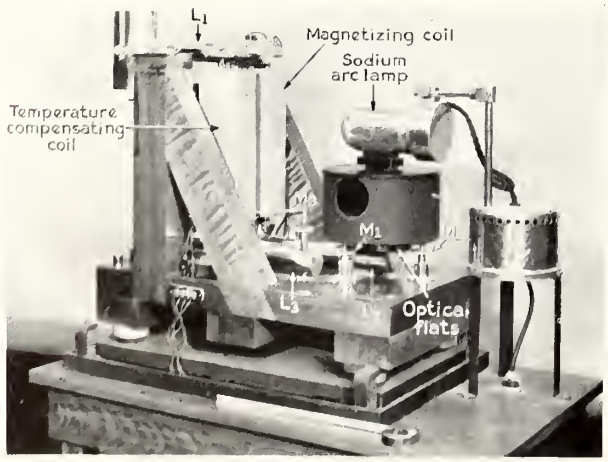


Fig. 2(*b*). The lever arm assembly of the magnetostriction test equipment

Trouble from external vibration is minimized by mounting the whole assembly on a heavily damped support. This damping, in conjunction with the inherent damping of the air film between the surfaces of the optical flats, is sufficient for excellent operation when the instrument is installed on the ground floor of the factory.

Samples and Sample Holders

The equipment is designed to test small Epstein strips. These strips are 25 cm long, 3 cm wide, and range in thickness from 0.020 to 0.065 cm.

The sample holders are nonmagnetic and are arranged to clamp only the middle 4-in. section of the sample and compensating strip. Thin phosphor bronze strips at each end of the sample holders form flexible hinges that slip into the thumb-screw-type clamps on the lever arms.

Flux Density Measurements

In order to eliminate the necessity of taking separate excitation curves on each sample to be tested, a photoelectric-recording-type fluxmeter[10] has been incorporated in the equipment. The fluxmeter element is somewhat similar to the Grassot fluxmeter.[11] This instrument allows the operator to record magnetostriction vs. flux-density curves directly. For continuous recording a telegraph key is connected in the recorder circuit so that the operator can electrically jog the recorder pen as each interference line passes the index point. Single-point measurements are taken by using the recorder as an indicating instrument. The flux coil is an integral part of the sample-clamp assembly and is located as shown in **Fig. 1(*a*)**.

Power Supply and General Assembly

The equipment operates directly from any 115-volt, 60-cycle line. A standard copper-oxide-rectifier power pack converts the 115-volt a-c to the low-voltage d-c required for the magnetostriction measurements. The schematic wiring diagram of the equipment is shown in **Fig. 3**. Air flux compensation for the search coil is incorporated in the magnetizing circuit. Provision is also made for demagnetizing the samples before each test.

(10) "The Photoelectric Recorder," by C. W. LaPierre, *Transactions, A.I.E.E.*, vol. 51, p. 226, March 1932.
"An Improved Photoelectric Recorder," by C. W. LaPierre, GENERAL ELECTRIC REVIEW, vol. 36, p. 271, June 1933.

(11) Karapetoff, *Experimental Electrical Engineering*, vol. 1, pp. 211–213, John Wiley & Sons, 1922.

A sensitive photoelectric amplifier with a mechanical counter was designed to take care of measurements requiring the counting of a large number of lines. Two photocells are used as shown in **Fig. 3**. One cell scans the lines crossing the reference index, while the other compensates for variations in the brilliancy of the light source.

The general assembly view of the complete measuring equipment is shown in **Fig. 4**.

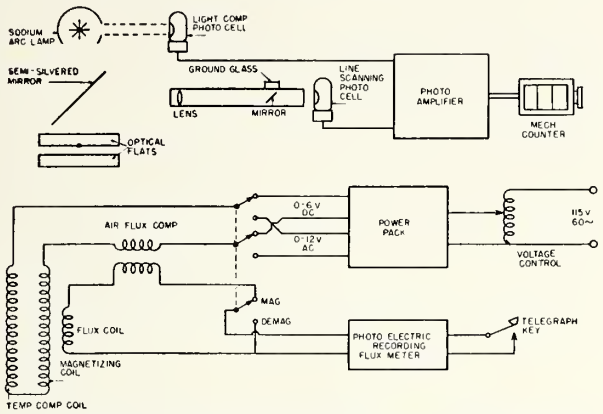


Fig. 3. Schematic arrangement of the power supply and line-scanning mechanism for the photoelectric-recording-type fluxmeter

the way the sample hangs in the clamp fixture may affect the results by an unknown factor.

Accumulated data indicate the following order of accuracy for an average magnetostriction measurement of $5(10)^{-6}$ inches per inch:

Reading error.....	$\pm 0.10(10)^{-6}$ in./in. or	$\pm$ 2.0 per cent
Repeat error.....	$\pm 0.50(10)^{-6}$ in./in. or	$\pm$10.0 per cent
Temperature error...	$\pm 0.30(10)^{-6}$ in./in. or	$\pm$ 6.0 per cent
Probable error...		$\pm$12.0 per cent

Based on limited experience, the probable error of the fluxmeter appears to be in the order of ± 2 per cent.

Results of Measurements

As a matter of routine procedure, all factory tests are made on completely demagnetized samples in the direction of an increasing magnetic field. Typical curves showing the effect of the silicon content in a particular type of core steel are shown in **Fig. 5(*a*)**.

Correlation between magnetostriction and audio sound is far from complete. The correlation found between audio sound measurements on final trans-

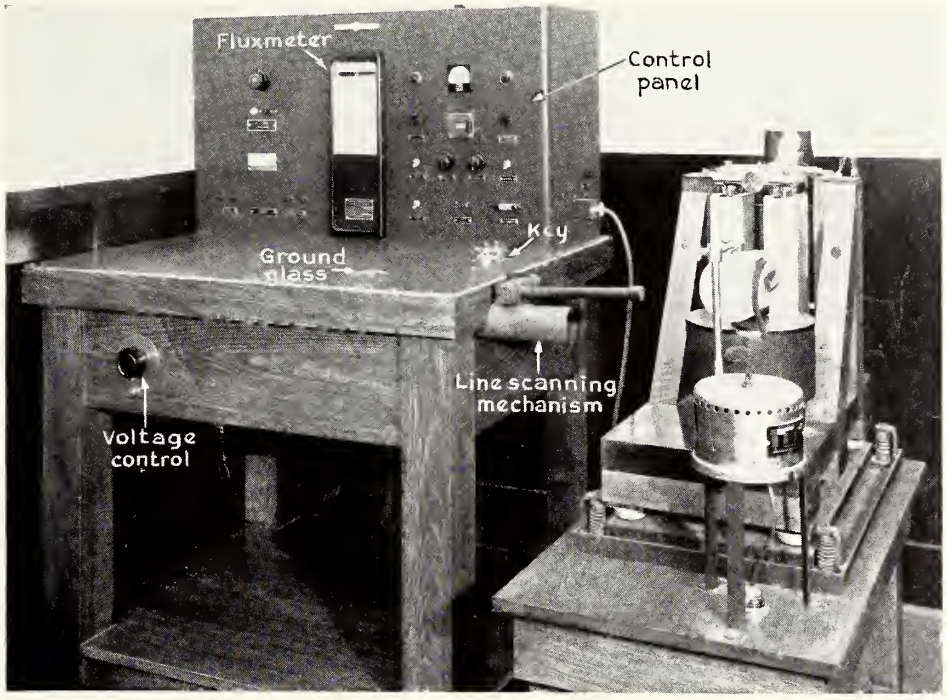


Fig. 4. General assembly of the complete magnetostriction measuring equipment

Range and Speed of Measurements

An elongation or contraction ranging from 0.5 to 80 $(10)^{-6}$ inches can be measured with the normal lever-arm ratio of 11.6-to-1.

A trained operator can measure from one to four samples an hour depending upon the amount of data desired.

Accuracy of Measurement

The absolute accuracy of this type of measurement is difficult to determine. Waviness of the sample or former cores and magnetostriction with respect to the silicon content of the steel is shown in **Fig. 5(*b*)**. Fortunately, methods of reducing magnetostriction generally reduce the effective losses in core material, although the exact correlation of magnetostriction vs. loss has not been determined. To obtain exact correlation between magnetostriction and sound data is extremely difficult. An exact history of all the core material, the effect of the core shape and core clamping as well as complete magnetostriction data are necessary before definite correlations can be

established. However, data collected to date indicate that the amount of audio sound can be anticipated from magnetostriction data, other variables being known or controlled.

Other Applications

Such an instrument can be readily adapted to other types of measurement such as the measurement of tensile strain and temperature coefficients of various materials. In general, it is adaptable to routine measurement of a change in length where the order of magnitude of measurement is extremely minute and normally requires special laboratory technique.

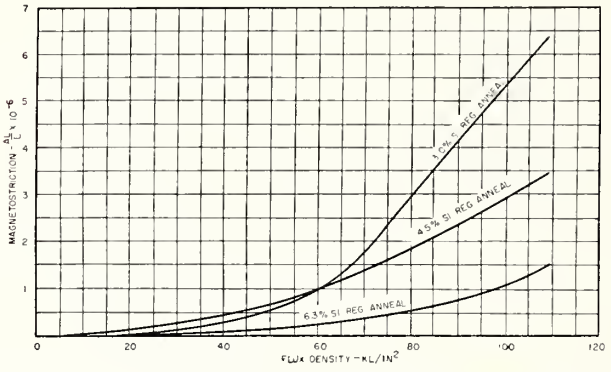


Fig. 5(*a*). Typical curves showing the effect of the silicon content in a particular type of core steel

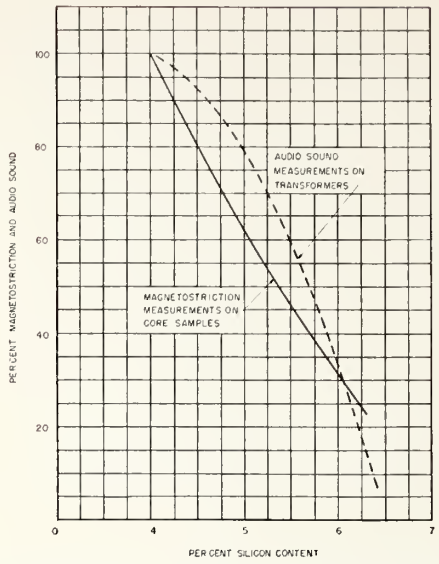

PERCENT MAGNETOSTRICTION AND AUDIO SOUND
PERCENT SILICON CONTENT
AUDIO SOUND MEASUREMENTS ON TRANSFORMERS
MAGNETOSTRICTION MEASUREMENTS ON CORE SAMPLES

Fig. 5(*b*). Curves showing the correlation found between audio sound measurements on final transformer cores and magnetostriction with respect to silicon content of the steel

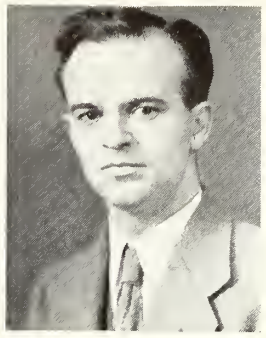
Conclusions

This method of measurement and associated equipment is a practical solution to the problem of magnetostriction measurements on a semi-production basis.

It has provided the metallurgist and design engineer with a rapid visual means of obtaining magnetostriction data that are essential to the design of quieter induction apparatus.

SPECTROGRAPHIC MEASUREMENTS

By BERNARD MULVEY
Schenectady Works Laboratory, General Electric Company



Bernard Mulvey

SPECTROGRAPHIC analysis is a physical method of chemical analysis which makes use of the fact that every element—when caused to emit light while it is in a vaporized condition—gives off light of a quality that is peculiar to that element. The prism or grating of the spectrograph receives the light from the sample and breaks it up into its component wavelengths or spectrum. This spectrum is recorded on a photographic plate. Since each element has its own particular spectrum, the presence of that element in the sample vapor can readily be detected by the appearance of that element's lines in the resultant spectrum. The intensity of the lines is an indication of the amount of the test element present.[1]

Quantitative spectrographic analysis finds its greatest application in the analysis of alloys containing elements in concentrations below five per cent. Above this value, for most elements, the intensity increases but little with an increase in concentration. However, in the higher percentage concentrations, ordinary chemical methods are most accurately and easily applied. Thus, the spectrograph finds a broad field of usefulness in the low ranges—from 5.0 down to 0.005 per cent—just where the chemist finds it most difficult to work.

In the Schenectady Works Laboratory, quantitative spectrographic analysis is used for a variety of materials, notably lead, steel, and some types of aluminum. The methods used for each type of material are essentially the same. Thus, the method as applied to lead alloys differs from that for steel alloys only in exposure time, spectrograph slit width, and a few other incidental details.

For example, consider the analysis of lead alloys. The elements to be determined are copper, bismuth, tin, silver, and antimony. The percentages of copper, silver, and bismuth will probably be in the range between 0.005 and 0.2 per cent; and the range for tin and antimony will likely be 0.01 to 2.0 per cent.

The sample is cut into two electrodes, each about one inch long and ¼ inch diameter. Then each electrode is sharpened to a slightly rounded point. The electrodes are next placed, with a 4-mm air gap between their pointed ends, in an insulated holder in front of the spectrograph slit. The electrodes are sparked by connecting them to a spark generator[2] which is essentially a condenser that is charged to about 20,000 volts and periodically discharged through an inductance and the electrode gap. The spark which jumps across the electrode gap illuminates a lens that is focussed on the slit of the spectrograph. An exposure of 30 sec is sufficient to register a satisfactory line spectrum on the photographic plate. After the first exposure, the plate is shifted to bring an unexposed portion into place and it is ready to receive the next spectrum. Fifteen to twenty spectra can be taken on one plate.

Before a quantitative analysis can be made, a series of standard electrodes must be sparked. These standards contain known amounts of the impurities as determined by previous chemical analysis. The procedure can be summarized as follows:

(1). A series of standard alloys containing varying amounts of the test elements is obtained.

(2). A calibration spectrum is run by sparking one of the standards and exposing with a rotating sector in front of the spectrograph slit.

The sector which is rotating at about 400 rpm is cut into seven steps, giving seven contiguous graded exposures the steps of which are graded in the ratio 100:50:25, etc. The purpose of the calibration spectrum is to determine the emulsion response[3] to varying amounts of light. A line of the base material (lead in this case) is used for this purpose.

(3). The standard alloys are then sparked together with the samples.

(4). After careful development and drying, the plate is evaluated by means of a densitometer. With this instrument, the operator measures the intensity of both the base and impurity lines with respect to the calibration curve that was obtained in operation (2). The ratio of intensities is a measure of the concentration.

(5). The intensity ratios obtained for the standard samples are plotted on logarithmic paper against the known concentrations and give an almost straight-line relationship. The intensity ratios of the unknowns are interpolated in this curve to obtain the concentration of the samples.

It is necessary to run the calibration and concentration curves only once for each batch of plates. Usually, however, each plate contains at least one standard to insure against error.

The accuracy of this method under carefully controlled conditions is from two to five per cent of the amount of the impurity. The following is a series of copper determinations made on a single sample of lead:

Spectrum	1	2	3	4	5
Per cent copper	0.061	0.061	0.060	0.059	0.061

Average 0.0603
Per cent maximum deviation.. 2.16

In view of the fact that simultaneous determinations for copper, silver, bismuth, tin, and antimony can be made in a matter of minutes, the economy of spectrographic analysis of lead will be appreciated. This, together with its accuracy, which is acceptable for most routine work, explains the increasing use of the spectrograph in industry for an ever-larger variety of materials.

(1) "Quantitative Spectrographic Analysis: Parts I and II," by J. T. Mireles Malpica, GENERAL ELECTRIC REVIEW, vol. 43, pp. 288 and 333, July and August 1940.

(2) "Electronic Spark Generator for Spectrographic Analysis," by J. T. Mireles Malpica and T. M. Berry, GENERAL ELECTRIC REVIEW, vol. 44, p. 563, October 1941.

(3) "Variations in Spectral Response of Spectrographic Plates," by J. T. Mireles Malpica, G. J. Steel, and B. Mulvey, *A.S.T.M.—Bulletin*, No. 109, p. 42, March 1941.

COLOR . . .

The increasing importance of color, from plastics through metals to respiratory enzymes, makes needful the qualitative and quantitative color analysis provided by the recording photoelectric spectrophotometer

By NORMAN F. BARNES
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Norman F. Barnes

FROM the standpoint of measuring and classifying an infinite number of colors in a way which permits each to retain its individuality, the spectrophotometric method offers an accurate and objective specification of color.

The basic instrument around which this method is built is the recording photoelectric spectrophotometer, a commercial design of which is shown in **Fig. 1**. The analysis of the color of an object consists in determining the percentage of light reflected, or transmitted as in the case of such materials as filters and solutions, by the object at each wavelength in the visible spectrum. Thus the sample to be measured is illuminated with spectrum light of substantially a single color, and the light reflected or transmitted by the sample, relative to a standard color, is automatically plotted against the wavelength of the incident light. This standard color, which forms a basis for color comparison, is a freshly smoked magnesium-oxide surface, chosen because of its uniform reflectance of practically all the incident light in the visible spectrum. This white color has further been accepted internationally as the standard for color measurements.

In the form of the spectrophotometric curve, a permanent record of the transmission or reflectance of each sample is obtained, and there is no need to depend upon the original sample. With color recorded in such a way, as an inherent property of the material, this means of objective specification gives results which are free from the numerous subjective errors of the human eye.

Color Specification

The specification of color in terms of the spectrophotometric curve can be greatly augmented by an evaluation of the sensation received by the eye when the sample is viewed under a certain set of conditions. It is a well accepted fact that the color appearance of a material, which is non-emitting and which is not self-luminous, is dependent upon three variables: the optical characteristics of the substance, the physical conditions of illumination under which the sample is observed, and the visual characteristics of the observer. The problem is further complicated since each one of these factors can cover a wide gamut of variation. Thus for a reflecting material, the stimulus produced at each wavelength and received by the eye will be a product of the energy of the radiation incident upon the sample and the reflectance of the material, both factors being evaluated at the particular wavelength considered. In order to transfer this stimulus into sensation, the relative wavelength sensitivity of the human eye to the incident radiation

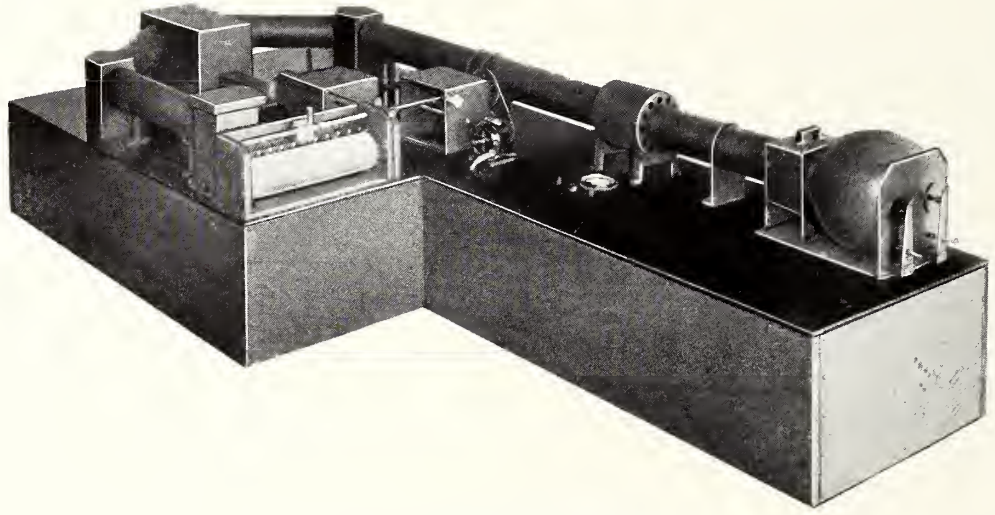


Fig. 1. The recording spectrophotometer

must be applied as the third factor in determining the color appearance of an object.

An immediate simplification is apparent in the form of restricting the conditions of illumination to a single set and of accepting standard visual characteristics of the normal observer. Accordingly, in 1931 the International Commission on Illumination (later referred to as I.C.I.) adopted as an internationally standardized illuminant for colorimetry, average daylight, referred to as Illuminant *C*. Two other standards were also adopted and are referred to as Illuminant *A*, representing the incandescent tungsten-lamp type of illumination, and Illuminant *B*, representing mean noon sunlight. Even prior to this Commission there had existed a universal agreement concerning the visibility function of the normal eye. This relationship is expressed as the relative brightness of equal amounts of energy at each wavelength in the visible spectrum.

Hence, with the illuminant and the visibility function thus standardized, it becomes possible to specify the color appearance of a material directly in terms of spectrophotometric data.

Tristimulus Values

It has been known for a number of years that a given color of light can be matched visually by the addition in proper proportions of three primary colors of lights. These primaries are defined in such a way that no two of them will combine to make the third and that the three will combine together to make white light. Otherwise, the choice of the primaries is perfectly arbitrary, and a set, for example, might consist of a red, a green, and a blue light. It is then possible to specify the color appearance of the original stimulus in terms of the equivalent stimuli of the three primaries used to produce a visual color match. These relative values of these stimuli are called tristimulus values and are referred to as *X*, *Y*, and *Z*, corresponding to the red, green, and blue primaries, respectively. Since one would obtain different tristimulus values for each set of primaries used, a set should be chosen such that the results are given in the most convenient form.

An additional requirement for the primaries chosen is that the gamut of colors that it is possible to produce through the mixtures of those three primaries must contain all real colors including the spectrum colors. The I.C.I. primaries have been accordingly chosen, and they have the further characteristic that the luminous reflectance of the sample is given directly by the *Y* tristimulus value. Thus *Y* will assume values from 0 to 100, expressed in per cent, corresponding to an absolute black and a perfect white respectively.

These values of *X*, *Y*, and *Z* can be obtained directly from the spectrophotometric curve by a simple integration process. The procedure involves the use of four functions: the spectrophotometric curve of the sample, the spectral distribution of the illuminant used for viewing the samples, the characteristics of the three I.C.I. primaries, and the visibility function of the standard observer. Since the latter two functions have been standardized and have permanent characteristics, they are combined together to form a single set of functions called the tristimulus functions for the normal observer, shown in the center group of curves in **Fig. 2**. These curves represent the amounts of the three I.C.I. primaries required to color-match spectrum radiation of unit energy.

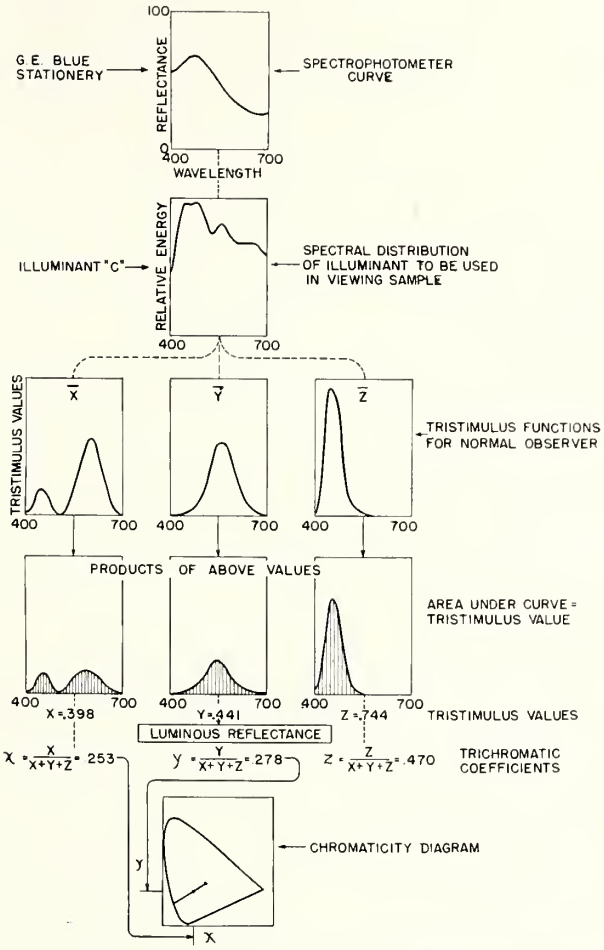


Fig. 2. The computation of chromaticity

A series of three triple products of each of these curves with the spectrophotometric curve and the spectral energy distribution of the illuminant gives rise to three additional curves, the areas under which are the tristimulus values. The process is shown schematically in **Fig. 2**. The actual calculation of the tristimulus values is greatly simplified through integral calculus to integrations of the spectrophotometric curve itself and to appropriate multiplying constants.

Trichromatic Coefficients

A color-classification system based solely upon the tristimulus values would necessarily be three dimensional in form and would therefore require a rather cumbersome and impractical three-dimensional graph for the comparison of different colors through their

tristimulus values. Furthermore, it is more often desirable to use a classification system which indicates the color appearance of an object when viewed under a set of standard conditions.

Fortunately it is possible to set up a system to satisfy this latter requirement and at the same time to obviate the awkwardness of the tristimulus system. To do this we introduce a new set of terms called trichromatic coefficients and define them mathematically as follows:

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

Thus the trichromatic coefficients represent the relative amounts of the three I.C.I. primaries used in obtaining a color match. It can be seen by an inspection of the above equations that it is necessary to specify but two of the trichromatic coefficients in order to completely define all three, since the sum of the three coefficients must be equal to one. As we shall presently see, the trichromatic coefficients determine the chromaticity or quality of the colored sample. Hence, the gamut of chromaticities can then be represented by a two-dimensional diagram in which the values of x are customarily plotted against those of y.[1]

Determination of Chromaticity

In order to better understand the interpretation of the chromaticity diagram, it will be necessary to introduce several new concepts.

We have already found that light can be matched by the proper mixture of three arbitrary primaries. In a similar manner, any color except purple can be matched by a mixture of white light, such as Illuminant *C*, and a spectrum color. The wavelength of this monochromatic spectrum color is called the dominant wavelength of the sample. Since the color purple is not present in the spectrum, it is, of course, impossible to specify that color in this manner. Consequently, in order to match purple, it is necessary to subtract from the white light a spectral color usually lying in the green region of the spectrum. This is accomplished by the addition of the green to the color to be matched until the combination is identical in appearance to the white light. Thus the dominant wavelength of a purple color is given in terms of the complementary color.

From the chromaticity diagram upon which the values of x and y are plotted, one can obtain directly the dominant wavelength of the sample as well as an additional quantity called the excitation purity, the latter representing the relative amount of the dominant wavelength spectrum color which would be required to produce a color match with white light. Purity values, expressed in per cent, will range from zero for the white light to 100 for spectrum colors.

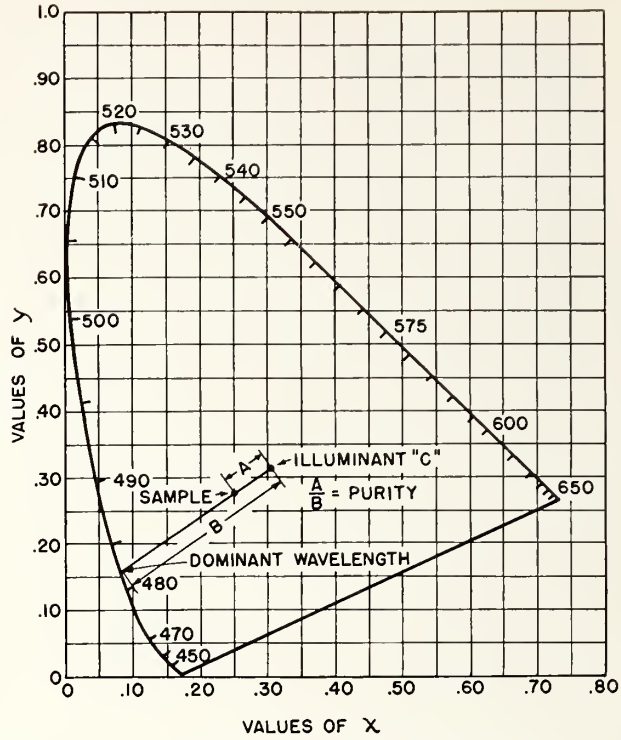


Fig. 3. The chromaticity diagram

The computation of chromaticity is shown in **Fig. 2**, and an enlarged chromaticity diagram is shown in **Fig. 3**. The attributes of dominant wavelength, luminous reflectance, and purity correspond closely to those in the psychological field relating to the actual color appearance of an object, and it has been shown how these values can be obtained from spectrophotometric curve itself.

Applications

The applications of spectrophotometry have grown at such a rapid pace that the spectrophotometer has become a powerful analytical tool both in the academic and industrial fields. Though the many ramifications in this field of measurement are so numerous that it would be impossible to mention them all here, a few of the more general types of measurements should be given. These can be divided into two groups: transmission measurements and reflection measurements.

In the former group the spectrophotometric curve gives the percent of light transmitted by the material as a continuous function of the wavelength of the light in the visible spectrum. This data can be used directly or it can be used to give additional information about the sample. For example, if one has a series of colored, homogeneous solutions differing only in the concentration of the coloring material, the values of the various concentrations can be calculated directly from the transmission values. Thus a new and sensitive method of quantitative analysis is available to the

[1] For detailed information, see *Handbook of Colorimetry*, prepared by Arthur C. Hardy and the Staff of the Color Measurements Laboratory, Massachusetts Institute of Technology (Cambridge: The Technology Press, 1936).

investigator. A qualitative means of identifying a material either as the sample itself or as an impurity or one of the component parts in a mixture is often possible through the mere inspection of the shape and position of the absorption bands characteristic of that

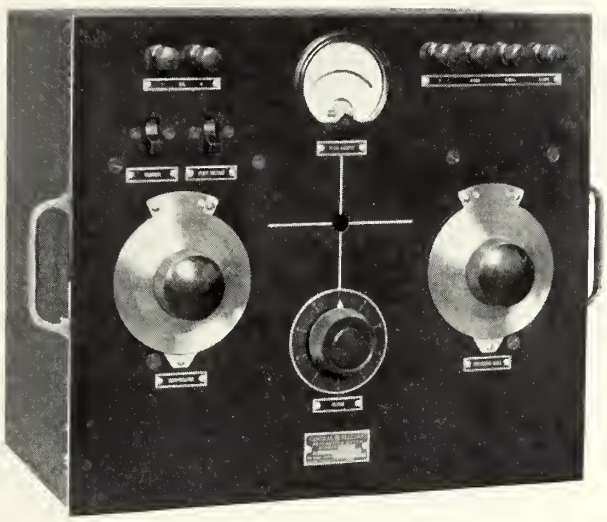


Fig. 4. The reflection meter

particular color. In many instances it is more desirable to record the optical density of a material rather than its transmission values. This can be done by a simple shift of cams in the instrument shown in **Fig. 1**.

Spectrophotometric qualitative and quantitative analysis methods apply equally well in the field of reflection measurements. An additional factor involved in this field is the physical nature of the reflecting surface. If this surface reflects light as a mirror does, the reflected light is referred to as being specularly reflected. On the other hand if the surface scatters the reflected light in all directions, the light is said to be diffusely reflected. Most materials have their surface characteristics between these two extremes, and it therefore becomes necessary to interpret the reflection values in terms of the surface characteristics.

For specific applications in the field of spectrophotometry, the list which follows is merely indicative of the ever increasing applications of this technique.

(A). Color matching, standardization, and control in the fields of:
- (1). Plastics
- (2). Printing ink
- (3). Rugs and textiles
- (4). Paints and varnishes
- (5). Dyes and pigments
- (6). Glass and liquid filters.

(B). Pharmaceutical analysis of:
- (1). Diethylstilbestrol
- (2). Testosterone
- (3). Alkaloidal drugs.

(C). Medical analysis of:
- (1). Pigments such as carotene, and melanoid in the human skin
- (2). Respiratory enzymes
- (3). Sulfhemoglobin, reduced and oxyhemoglobin in the blood stream
- (4). Sex hormones
- (5). Distribution of venus and arterial blood supply in the circulatory system.

(D). Photo-chemical reactions of fading and bleaching.

(E). Qualitative and quantitative color analysis, such as colorimetric determination of:
- (1). Zirconium, hafnium, and titanium
- (2). Copper and zinc
- (3). Molybdenum and vanadium.

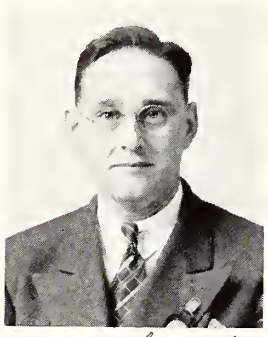
Reflection Meter

An instrument which has proved to be capable of very satisfactory measurements for certain specific applications is the reflection meter shown in **Fig. 4**. This instrument was designed particularly for use in the pulp and paper industry, and will measure reflection values for nine different colors in the visible region. A series of sharpcutting filters determines the wavelength bands at the light used for the reflection measurements. This instrument is particularly applicable to samples of relatively high luminous reflectance and low purity.

THERMOCOUPLES . . .

Calibrating thermocouples at fixed points with tin, lead, and aluminum freezing-point furnaces modeled after those of the Bureau of Standards. Also, sulphur furnaces for immersions at 4 to 12 in.—temperature variation over this range is approx. 0.06 F

By H. B. LANCASTER and A. W. BRUNOT
Thomson Laboratory, General Electric Company



Harry B. Lancaster

THE increasing use of thermocouples as a temperature-measuring medium created the demand for proper calibrating facilities. As a result it was decided to obtain apparatus that would enable reliable temperature standards to be maintained. This would assure proper calibration of the thermoeouples in use.

The range of ealibration desired was from 32 F to 1300 F, and at about 850 F it was desired that thermocouples be checked at various immersions for use in thermocouple wells of various depths. The wells in use were from about 5 in. to 10 in. deep, so a range of 4 to 12 in. was chosen.

A W Brunot

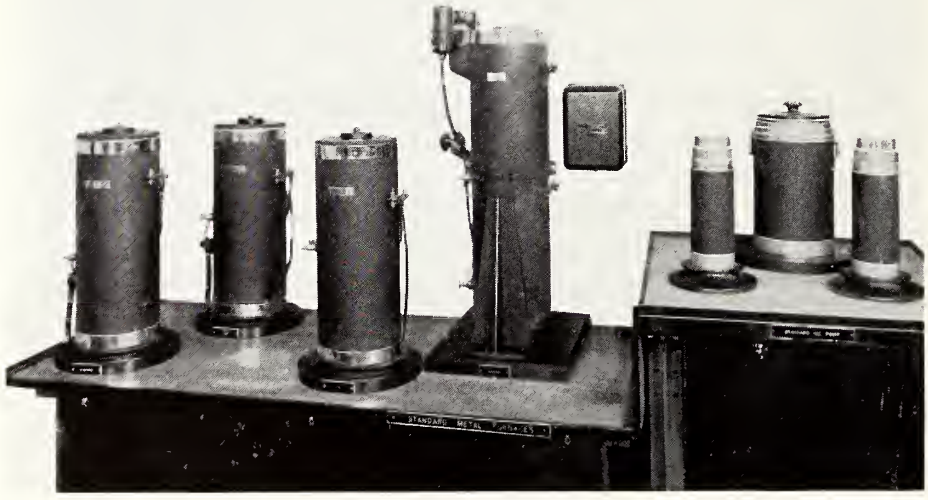


Fig. 1. Furnaces for thermocouple calibration

Within this range it seemed advisable to usc the following fixed-temperature points:* The ice point (32 F), thc tin freezing point (449.37 F), the lead freezing point (621.23 F), the sulphur vapor point (831 F to 834 F depending on barometric pressure), and thc aluminum freezing point (1220.27 F).

The calibrating furnaecs used are shown in **Fig. 1**. They consist of three freezing-point furnaees, the sulphur-vapor furnaec and the ice-point vaeuum bottle.

Freezing-point Furnaces

In construction, thc tin, lead, and aluminum freezing-point furnaces are similar to those described in the Bureau of Standards Researeh paper RP768. A cross seetion is shown in **Fig. 2**.

A separate eleetric furnaee of identical design is used for eaeh metal. The heater tube is of alundum (R.A. 98) 14 in. long with an inside diameter of 2 in. and a wall thiekness of $\frac{3}{8}$ in. This tube is wound on the outside with about 70 turns of No. 14 B & S gage, Chromel "A" wirc which is embedded in alundum eement. The graphite crucible containing the metal and the thermocouple protecting tube is supported by Sil-O-Cel cylinders. Two graphite diaphragms are plaeed above the crucible eontaining the freezing-point samples. This is done to minimize the oxidation

*These freezing-point values are taken from samples received from National Bureau of Standards.

of the sample and to promote better temperature uniformity within the metal bath.

The furnace shell is made of sheet steel, rolled and formed into a cylinder. The space between the heating tube and the outside shell is filled with Sil-O-Cel No. 3 insulation. The furnace top is closed with a clay graphite plate. The hot junction of a

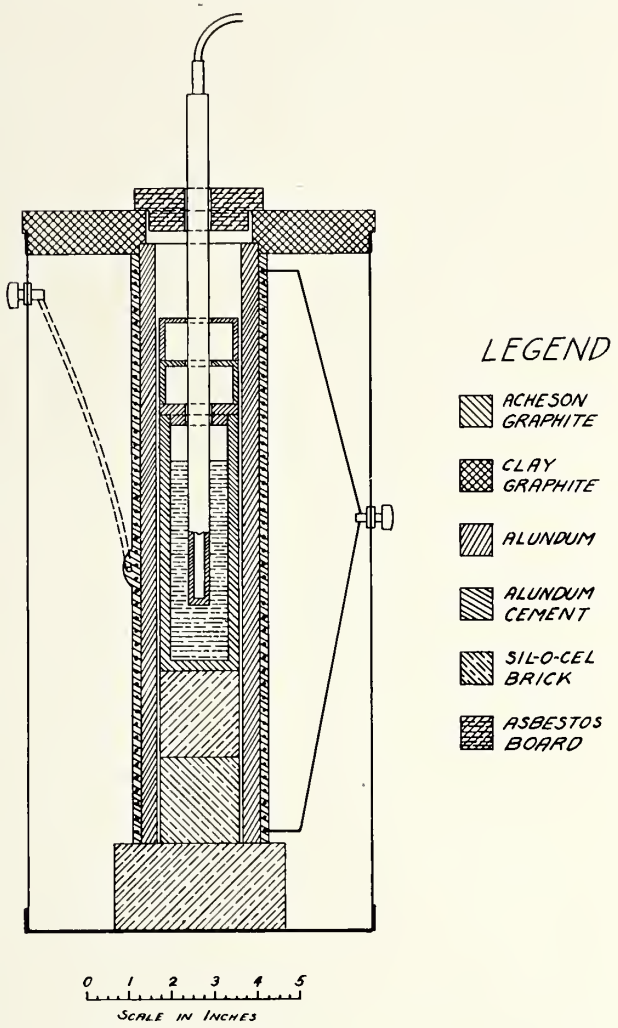


Fig. 2. Cross section of freezing-point furnace

chromel P.-alumel, No. 18 B & S gage, thermocouple is embedded in the heating element and the wires brought out to binding posts. This is used as an approximate means of controlling the temperature of the furnace to prevent overheating of the furnace winding, and to hold the metal just above the freezing point.

To calibrate the thermocouple at the metal freezing point, the thermocouple protection tube, with the thermocouple within, is passed through the furnace cover, diaphragms, crucible cover and finally rests on the freezing-point sample. The freezing-point sample is heated to about 20 F above the freezing point and held there for 15 min. After agitating the molten metal with the protection tube the furnace is shut off and the thermocouple assembly is clamped so that the hot junction of the thermocouple is about 1¼ in. from the bottom of the crucible. This leaves approximately 4 in. of the thermocouple in the metal and 6 in. more within the furnace.

Readings of the millivoltage of the thermocouple are taken, giving a time-temperature curve, which enables the freezing point of the metal to be determined. Readings of the millivoltage are taken on a five-dial precision potentiometer which is periodically checked against a laboratory-standard potentiometer with a Bureau of Standards calibration. This certifies accuracy to within 0.002 millivolts.

The metals used are certified Bureau of Standards samples. Each freezing point is double checked using a thermometer bridge and platinum-resistance thermometers. Both the thermometer bridge and resistance thermometers have Bureau of Standards certificates.

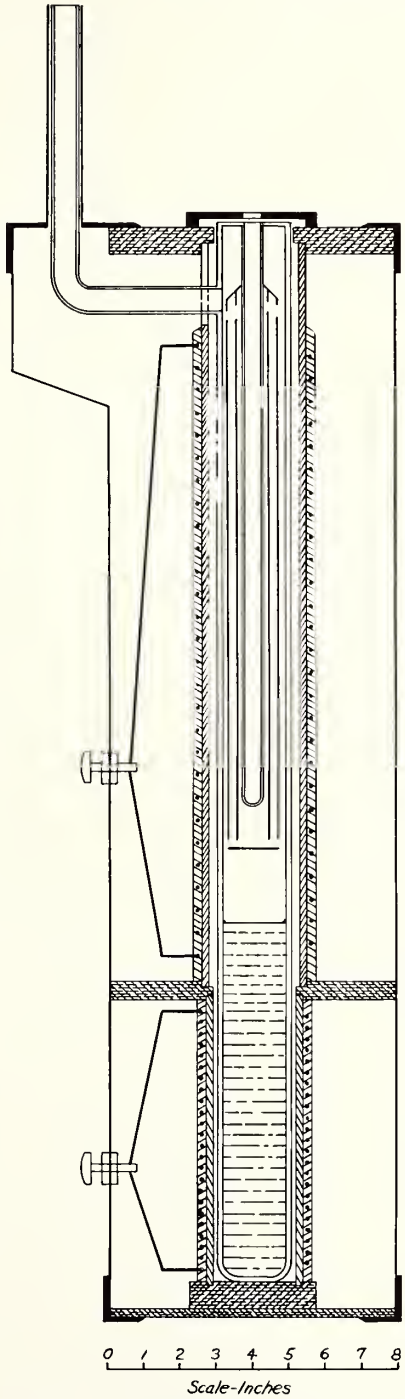


Fig. 3. Cross section of sulphur-vapor furnace

By this method the freezing points of the samples are checked within 0.04 F.

For ice point, quart vacuum bottles filled with crushed ice are used. This point is periodically checked using the thermometer bridge and platinum-resistance thermometers.

Sulphur-vapor-point Furnace

The sulphur-vapor-point furnaces, which were in use at the time this work was started, were all constructed with a single vertical tube for both the boiling and condensing of the sulphur. As a result of this construction, it was necessary to insert the thermocouple in the protection tube to same depth before it was in the region of sulphur vapor. Since it was desirable to calibrate thermocouples at immersions of 4 to 12 in., it was necessary to design the furnace to obtain these conditions. The resulting

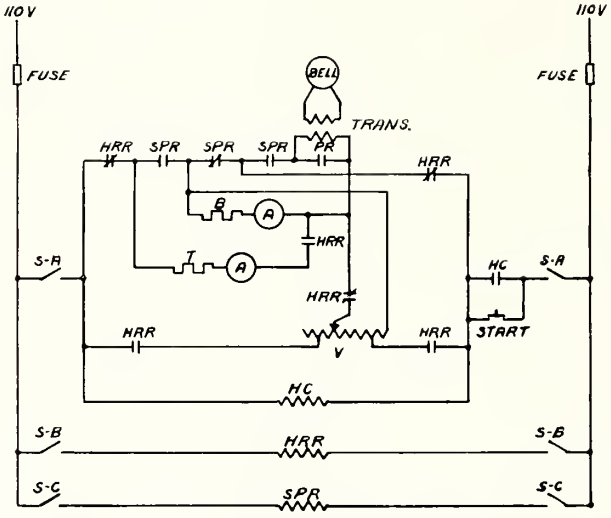


Fig. 4. Elementary wiring diagram for sulphur-vapor furnace

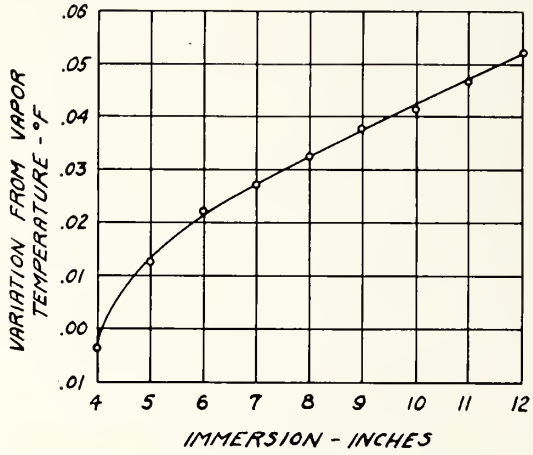


Fig. 5. Variation of indicated sulphur-vapor temperature with immersion

design is shown in Fig. 3, and it is seen that, by having a separate condensing tube, it is possible to obtain low immersions of the thermocouple and still be in the region of sulphur vapor.

The boiling tube is of Pyrex. It is 2 in. in outside diameter with a $\frac{3}{32}$-in. wall and is about 29 in. long. The protection tube is of Pyrex and is 16½ in. long with an inside diameter of 0.390 in. Two radiation shields of aluminum are fitted over the protection tube and are supported by a small neck in the main boiling tube. To eliminate leakage the protection tube is fused to the main boiling tube at the top, and the only vent to the air is the condensing tube which extends about 6 in. above the furnace.

The boiling tube is placed inside of a two-piece alundum core. The bottom section is 2¼-in. inside diameter by 8 in. long and carries the main heating unit, which consists of about 20 ohms of No. 21 Chromel "A" wire. The top section of this core is 2½-in. inside diameter by 21 in. long and carries a secondary unit consisting of about 30 ohms of No. 21 Chromel "A" wire. Both core sections are covered with alundum cement after winding.

The core and tube assembly is placed in a sheet-metal case closed at the top and bottom with asbestos board. The space surrounding the core is filled with Sil-O-Cel No. 3 insulation. To protect the top of the boiling tube, a metal plate containing a hole to admit the thermocouple is placed in the center of the top cover. A few sheets of asbestos paper are used between the boiling tube and the metal cover to reduce the thermal shock which might occur if the tube were heated more rapidly than the plate.

The condensing tube is mounted between a light source and a photoelectric relay. This is wired into the control circuit to shut off the furnace if the sulphur level rises too high in the condensing tube. This prevents the furnace from boiling over.

It has been found that sufficient U.S.P. sulphur powder must be used in the boiling tube to bring the liquid level to a depth of about 10 in. A low sulphur level will produce erratic readings due to superheating of the vapor.

The control circuit is shown in the elementary diagram in Fig. 4. In operating this furnace certain precautions must be taken to eliminate the possibility of breaking the boiling tube. When starting, the furnace is first placed in a vertical position and turned on by closing switch *A* and pushing the start button. This places both furnace windings in series and gives a low, uniformly distributed heat which causes the sulphur to melt. After about 30 min the photocell is put into the circuit and then switch *C* is closed, putting both heating units in parallel. This raises the heat input and brings the sulphur to a boil. As the condensate level rises in the condensing tube the light beam is interrupted and the photocell relay opens, shutting down the furnace and ringing the alarm bell.

After the bell rings, switch *C* is opened and switch *B* is closed. This cuts out the secondary heating unit and puts the main heating unit across the output of the autotransformer arrangement. By adjusting the current in the main heating unit, the sulphur-condensate line is maintained about 2 in. above the boiling tube. When the furnace is shut off, it is rotated

on its mounting brackets so that it lays at an angle of less than 30° to the horizontal. This allows the sulphur to solidify along the side of the boiling tube.

If desired the furnace may be left overnight with switch A closed, and B and C open. This will keep the sulphur molten but not boiling. If power should fail the holding coil will open and prevent the furnace from operating again. This is necessary, since if the sulphur solidifies in the tube while it is in a vertical position, the tube may crack if it is again started. If the sulphur solidifies while the tube is in a vertical position, it is necessary to remove the tube from the furnace and melt the sulphur with a gas flame starting at the top of the tube and working to the bottom. It has been found that this will eliminate breakage of the boiling tube.

The sulphur furnace is calibrated using a four-lead potential-terminal-type platinum-resistance thermometer and an improved Mueller bridge reading to 0.0001 ohms. Both the resistance thermometer and bridge have been certified by the Bureau of Standards. For all measurements the bridge is held at 35.1 C ± 0.01 C by means of a thermostatic controller, and the resistance thermometer is checked at the ice point before and after each series of readings, the resistance being measured in both the normal and reversed positions of the bridge.

The barometric pressure is read at regular intervals throughout any test and this is used to determine the sulphur-vapor point from the formula.*

$$t_p = 832.28 + 0.16345\ (p-760) - 0.0000856\ (p-760)^2 + 0.000000079\ (p-760)^3$$

Where t_p is the temperature in degrees F and p is the barometric pressure in mm of Hg.

Results

It is assumed that the temperature calculated from the above equation is the true temperature of the sulphur-vapor point. This value is compared with the temperature determined from the resistance thermometer using Callendar's equation with the constants supplied by the Bureau of Standards. **Fig. 5** shows the results of an exploration to determine the variation in observed error with variation in immersion. This test was made in one series of runs. The only variation was in the measured resistance and a slight change in barometric pressure. It is apparent that this furnace gives a temperature reading of within 0.06 F for immersion of 4 to 12 in. Since the accuracy which is desired is only ±0.2 F the correction shown in **Fig. 5** may be neglected and the vapor-point temperature for all immersions from 4 to 12 in. can be taken directly from the given equation.

*Proceedings of the American Academy of Arts and Sciences, vol. 71, January 1937.

COOLING, DEHUMIDIFYING

Measuring the cooling and dehumidifying capacities of air-conditioning equipment by the electric-calorimeter method presents decided advantages over the conventional method

By HARRY A. WHITESEL
Air Conditioning and Commercial Refrigeration Department
General Electric Company

IN THE development of air-conditioning equipment the problem of measuring the cooling and dehumidifying capacities of refrigerating systems is prominent. Specifically, the problem may be stated as follows:

(a). Determination of cooling and dehumidifying capacities with small wet-bulb temperature differences.

(b). Proper compensation for air leaks and jacket losses.

(c). Requirements of low testing costs.

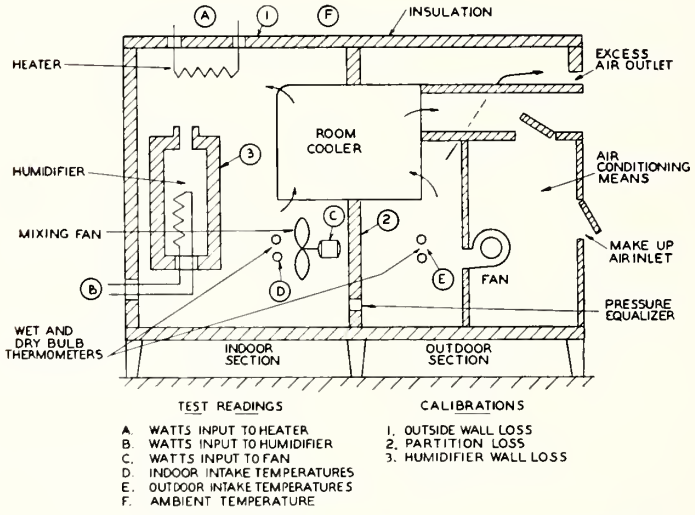


Fig. 1. Schematic arrangement of room-cooler electric calorimeter

A solution is available through the use of an electric calorimeter which employs a simple and direct method of measurement. The calorimeter can be used to determine the capacities of such apparatus as forced-air commercial evaporators, finned-tube heat exchangers, and room coolers. The fundamental principle has been described in an earlier article by the author.(1)

The calorimeter method was first applied to the testing of air-cooled room coolers. These are self-contained devices having two air circuits, the indoor circuit which is the air to be conditioned, and the outdoor circuit which removes the heat. The present article deals with this application.

(1)"A New Method of Load Testing for Domestic Refrigerators," by H. A. Whitesel, *Refrigerating Engineering*, vol. 27, p. 240, May 1934.

The Electric Calorimeter

Fig. 1 shows a schematic arrangement of an electric calorimeter based on the proposed method of testing. During a test the cooler is run continuously while the dry- and wet-bulb temperatures are held at any desired values at the unit inlet by adjustment of power inputs to the indoor heater and the humidifier, with the air-mixing fan running. The net cooling and dehumidifying capacities are equal and opposite to the corresponding loads that must be added to balance them. The humidifier jacket losses, which are determined from a calibration constant and temperature difference, must be subtracted from the humidifier power input to obtain the heat consumed in boiling the water. No water is evaporated by air circulation, since the humidifier outlet is small. The water is brought to the boiling temperature before the test is started, and none is added during the test.

The latent capacity is the pounds evaporated per hour multiplied by the latent heat per pound at the temperature at which the water condenses on the evaporator. The sensible heat is obtained from the algebraic sum of the heater and the mixing-fan inputs, the humidifier and calorimeter wall losses, the main partition loss, and the sensible heat of the steam condensed.

The outdoor section of the calorimeter conditions air to the desired wet- and dry-bulb temperatures and circulates an excess past the room-cooler outdoor intake. Atmospheric pressure is assured at this point by the large excess air outlet. Two adjustable doors make it possible to control the outdoor-conditioner intake temperature by selection of air partly from the room-cooler exhaust and partly from the ambient. The small opening in the indoor-to-outdoor partition provides pressure equilization, as would miscellaneous openings in a field installation.

Although the primary purpose of running a performance test on a room cooler is to determine its cooling and dehumidifying capacities, it is sometimes desirable—particularly for design purposes and for checking—to measure air flows and inlet and discharge wet- and dry-bulb temperatures. **Fig. 2** shows a compact design of calorimeter which combines reliable facilities for making such measurements with the direct wattmeter method of measuring capacities.

Before temperatures are taken in the calorimeter shown in **Fig. 2**, the air is mixed by means of rectangular solid baffles, one extending from each of the four sides of the air passageways. Tests on different types of mixers show that these give excellent results. Perforated metal screens are located at various places to spread out the air flow and make it more uniform. A pair of orifices in a flat plate is used to measure air flow, by the static-pressure method, after being calibrated in place by the use of standard nozzles. The room-cooler discharge air temperatures are read by one pair of wet- and dry-bulb thermometers placed in the high-velocity air stream in front of each orifice. The intake temperatures are read in high-velocity air streams at each of the discharges of the calorimeter double-type fans.

Still referring to **Fig. 2**, the fan motors are operated on alternating-current power for convenience, and the air flow is controlled by means of dampers. The flows are adjusted to give atmospheric pressure at the room-cooler discharges, as determined by draft gages connected to static pressure points. To assure atmospheric pressure at the condenser air intake, a small amount of outside make-up air is admitted into the condenser conditioner through a small opening ahead of the cooling coil, where the pressure is below atmospheric. A larger opening, or pressure equalizer, is then placed in the condenser-intake-compartment outer wall to permit passage of excess air. An opening, or pressure equalizer, is also placed in the indoor-to-outdoor partition to insure atmsopheric pressure at the indoor intake. The pipe which draws air from the top center of the calorimeter and returns it to the suction side of the indoor fan is for the purpose of recirculating a portion of the intake air through the room-cooler compartment. This assures that any warm air that may enter the top of the room-cooler compartment through the pressure equalizer will not affect the temperature of the air entering the unit.

Fortunately, the two largest heat-loss constants can be determined by calibration, using wattmeters. The humidifier is calibrated by sealing its outlets and applying enough power to hold atmospheric pressure with air vented. Any desired average air temperature may be held, and the indoor calorimeter fans should be run. The heat loss constant is equal to the humidifier power input, expressed in heat units, divided by the temperature difference between the steam and the air surrounding the humidifier.

The calorimeter outer walls are calibrated for heat loss by applying power to the indoor air heaters, with indoor calorimeter fan running, to give any desired temperature differential above ambient surrounding the calorimeter. The temperature differential across the indoor-to-outdoor partition should be held at zero with all openings filled in and sealed. The outer wall heat loss constant is equal to the total heat input to the air heaters and the fan motor divided by the average temperature difference between indoor air and outside ambient. The partition constant is so small that it can best be determined by calculation.

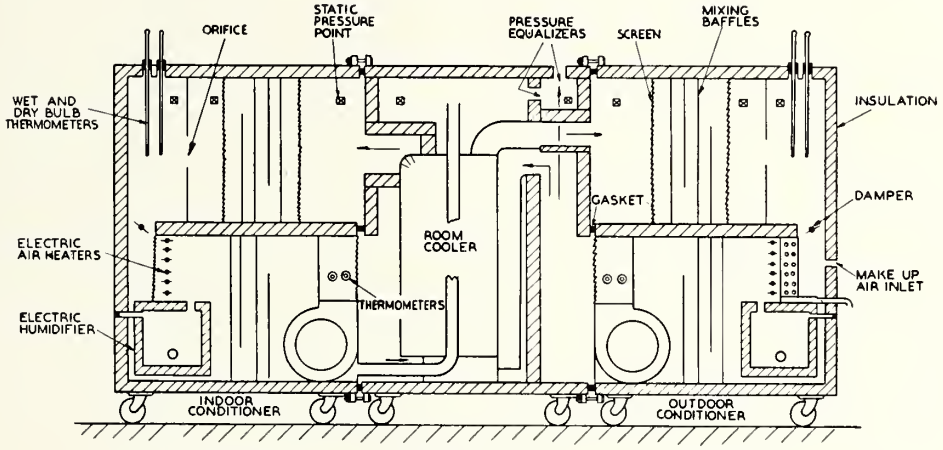


Fig. 2. Cross section of room-cooler electric calorimeter showing method of including air-flow and temperature measurements

The design shown in **Fig. 2** is very flexible. The two conditioners are alike except that the outdoor one is equipped with a cooling coil that connects to a remote condensing unit. The room-cooler discharge connections and the indoor-to-outdoor partition are specially built for the particular unit being tested. These are assembled and sealed in place while the central section of the calorimeter is separated from the end sections and rolled out so that work can be done on it easily. The inlet openings to the calorimeter conditioners are large enough to accommodate any type of discharge from the room and outdoor sides of the room cooler. Likewise, any type of inlet on the room or outdoor side of the room cooler can be accommodated, since these are surrounded by chambers that receive air from the conditioners. The calorimeter lining must be air-tight and should preferably be of a welded sheet-steel construction.

Comparison of Electric Calorimeter and Conventional Methods

The essential differences between the electric-calorimeter method and the conventional method of testing room coolers[2] are indicated in Table I.

[2] "Proposed Standard Methods of Rating and Testing Self-contained Air Conditioning Units for Comfort Cooling," American Society of Refrigerating Engineers' pamphlet, May 23, 1939.

TABLE I

COMPARISON OF ROOM COOLER TEST METHODS

Conventional Method	Electric Calorimeter Method
(a). Indoor air circulated through room cooler and not returned.	(a). Indoor air recirculated through room cooler.
(b). Insulated box with large opening surrounds indoor side of unit, except air discharge, and acts as passageway for intake air whose temperatures are taken at the opening.	(b). Insulated box surrounds indoor side of unit and acts as small room equipped with electric heater and electric humidifier.
(c). Primary capacities obtained from evaporator air flow and change in heat content as determined by wet- and dry-bulb temperatures.	(c). Primary capacities obtained from wattmeter readings of power input to heater and humidifier.
(d). Confirming capacities obtained through subtracting power input from condenser heat as determined from condenser air flow and wet- and dry-bulb temperatures.	(d). Comparative capacities obtained from evaporator air flow and wet- and dry-bulb temperatures.
(e). Test room with controlled ambient required.	(e). No test room required.

Table II gives the capacity, and wet- and dry-bulb temperature data from five tests on two room coolers of a well-known make when carefully tested by the conventional method.[3] Tests 1 and 3 were run at rating conditions, while the indoor conditions were brought up equal to the outdoor for Tests 2, 4, and 5. Test 5 is a duplicate of Test 4. None of the first three tests is satisfactory, since the confirming test result vary more than 5 per cent from the primary test results.

Much better agreement is obtained when the indoor and outdoor temperature conditions are the same. This is what one would theoretically expect with certain types of air leaks, such as a leak between the indoor space and the condenser circuit. Examination of the machines showed that there were leaks between the condenser and indoor circuits. In the tests with the same indoor and outdoor conditions any possibility of trouble from mixing in the outdoor conditioner was also eliminated, since outdoor air was drawn directly from the test room in this case. However, a survey of outdoor intake wet- and dry-bulb temperatures in the tests where the conditioner was used failed to reveal any serious trouble with mixing.

Although bringing indoor and outdoor conditions together gave sufficient agreement between primary and confirming tests for Machine B, it did not give satisfactory results for Machine A. The additional trouble was probably due to difficulties encountered in measuring small wet-bulb differences. It is not surprising that the results do not check, considering the small wet-bulb temperature difference with Machine A and the fact that the confirming test is taken as the difference between two large quantities, the condenser heat and the power input. It can be seen that as the wet-bulb temperature differences become greater, the accuracy becomes better. This explains why better confirming tests are had with Machine B than Machine A and why the primary capacities in Tests 4 and 5 agree better than the confirming capacities.

The results given in Table II are not typical, but

[3] "Temperature Measurements in Air Conditioning," by H. A. Whitesel, *Temperature, Its Measurement and Control in Science and Industry*, p. 847, Reinhold, N. Y., 1941.

TABLE II

DATA SELECTED TO ILLUSTRATE OCCASIONAL DIFFICULTIES WITH CONVENTIONAL ROOM-COOLER TEST METHOD

	MACHINE A		MACHINE B		
Test	1	2	3	4	5
Operating Conditions	Standard Rating	Indoor same as Outdoor	Standard Rating	Indoor same as Outdoor	Indoor same as Outdoor
Indoor Air Temperatures:					
Inlet, dry bulb, F	79.9	95.0	80.0	94.8	94.8
wet bulb, F	67.1	75.1	67.3	75.2	75.3
Outlet, dry bulb, F	65.1	74.1	66.4	75.5	75.9
wet bulb, F	60.3	68.0	61.6	68.5	68.9
Difference, dry bulb, F	14.8	20.9	13.6	19.3	18.9
wet bulb, F	6.8	7.1	5.7	6.7	6.4
Outdoor Air Temperatures:					
Inlet, dry bulb, F	95.3	94.6	95.2	94.7	94.6
wet bulb, F	74.9	75.0	75.1	75.0	75.1
Outlet, dry bulb, F	103.0	105.5	110.0	113.5	113.5
wet bulb, F	77.1	77.9	79.1	80.2	80.2
Difference, dry bulb, F	7.7	10.9	14.8	18.6	18.9
wet bulb, F	2.2	2.9	4.0	5.2	5.1
Net Total Capacities Determined from Wet-bulb Temperatures:					
Primary (evaporator), %	100.0	123.3	100.0	138.0	133.6
Confirming (condenser), %	66.8	108.8	92.2	137.6	131.1
Primary Capacity Breakdown:					
Sensible, by dry bulb, %	72.3	101.4	77.5	110.6	108.3
Latent, by difference, %	27.7	21.9	22.5	27.4	25.3

have been included to show what occasionally is encountered in room-cooler testing. There seems to be considerable trouble due to air leaks and small wet-bulb temperature differences, and perhaps some is due to inadequate air mixing.

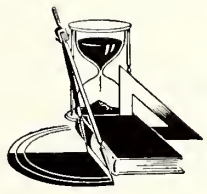
In the electric-calorimeter method the wet-bulb measurement does not enter into the primary-capacity determinations. These capacities are measured by wattmeter readings. There is much less chance for error than in the conventional method where capacities are based on double readings of air flow and temperature differences. In both methods, the wet-bulb temperatures affect operating conditions, but, as can be seen from Table II, a certain error in evaporator-inlet wet-bulb measurement is several times as serious when used as a basis for calculating capacity as when used only for holding operating conditions.

The electric calorimeter properly compensates for air leaks of all types and jacket losses in the primary-capacity measurement. If heat is added to or subtracted from the indoor space in any manner, the sensible heat and humidification loads must be made correspondingly less or more to obtain a balance. In the case of an air leak into the condenser circuit from the room, outdoor air is drawn into the indoor space through the pressure equalizer, just as it would be drawn in through miscellaneous openings in a field installation. This effect is not accounted for in the conventional primary-capacity measurement, since evaporator air flow and temperatures are not affected. Primary capacities obtained by the wattmeter method with the **Fig. 2** calorimeter may be checked against capacities from indoor air flow and temperatures; but it should be remembered that the latter values may be in error due to air leaks.

The controlled ambient test room is unnecessary with the electric calorimeter method, since the indoor compartment itself acts like a room and has a means of controlling temperature and humidity. Slight changes in ambient temperature surrounding the calorimeter have very little effect on the temperature inside because of low heat leakage through the insulated walls. The temperature and humidity can be controlled very easily during the test by holding constant the power input to the heater and humidifier with hand-operated voltage regulators. It is more difficult to obtain the desired accuracy when the test room is used as a source of inlet air with controlled temperature and humidity, as is done in the conventional method. This is particularly true since automatic control systems, as generally used for test rooms, operate on cycles.

Further test time is lost in the typical conventional setup due to the use of rather elaborate equipment. It is obvious that the initial cost of equipment as well as the operating cost for this type of testing is considerably more than with the electric calorimeter.

The author wishes to acknowledge the help of R. H. McKibben, who read and constructively criticized the manuscript.



SOUND . . .

Accurate sound-measuring equipment aids in the reduction of unwanted noise, as well as in the production of desired sounds

By WALTER MIKELSON
General Engineering Laboratory, General Electric Company

"I MUST move to the country immediately as the noise in the city is getting unbearable. As many as six ox carts have passed by my window today."

These could undoubtedly have been the words of a prominent Revolutionary Bostonian, busily engaged at his occupation in his city dwelling. Since that time countless new domestic, office, and industrial noises have made their appearance, noises which dwarf his ox carts into insignificance. In the home, appliances such as washing machines, refrigerators, food-mixers, and automatic furnaces have sprung into being. In the offices and factories, typewriters, fans, calculating machines, duplicating machines, and factory machinery pour forth their noises to annoy, distract, and lessen the efficiency of the personnel. In the streets outside the home the rumbling of automobiles, busses, trucks, and street cars is continually disturbing the person who would be unlucky enough to live or work in its presence.

More timely, our present all-out war effort has introduced new problems where quietness is of the utmost importance. Submarines must be noiseless if they are to creep around enemy vessels without being detected. Surface vessels and airplanes must be as quiet as possible to make life more bearable and to minimize mistakes and errors due to poor intelligibility of commands.

On the other hand there are occasions when loud sounds are desirable. To cite a recent example, air-raid sirens and other signal systems must be designed so they can be heard by people busily engaged at their daily chores in locations where there may already be a high background noise level above which the siren sound must penetrate. Deck speakers on board ships must be designed so that they can put out enough sound to be heard distinctly above the roar of the ship's auxiliaries.

All of these developments have led to the need for accurate sound-measuring equipment, which is essential for the study, control, and cataloging of data on the sound output of the many devices the country is now building and using. Such sound-measuring equipment includes primarily:

(1). Sound-level meter
(2). Wave analyzer

Since sound is a pulsation of air pressure above and below atmospheric, a sound source is generally a vibrating surface of some sort. Hence the study and elimination of vibration is also of primary importance in dealing with this problem. The instruments involved in the measurement of vibration are:

(1). Vibration meter
(2). Wave analyzer

The sound or vibration pickups generate electric voltages which are amplified and made to actuate indicating instruments. Each measures the total disturbance present, including all the frequencies which may be involved in the sound or vibration. With the wave analyzer, it is possible to break the sound or vibration into its various frequency components and measure the intensity of each individual component. Thus, the disturbance can be tracked more easily to its source. It is the purpose of this article to discuss only the measurement of total sound with the sound-level meter.

TERMINOLOGY

Although the use of sound-measuring instruments is beginning to be widespread at the present time, they have been in existence only a limited number of years. Hence, it would seem desirable, at this point, to define the various terms used in speaking of sound and its characteristics. The terms are listed as follows:

Term	Type	Units
Sound intensity	Physical	Watts per sq cm
Sound-intensity level	Physical	Decibels (above 10^{-16} watts per sq cm)
Sound pressure	Physical	Dynes per sq cm
Sound-pressure level	Physical	Decibels (above 0.000204 dynes per sq cm)
Loudness level	Physiological (relative)	Phons
Loudness	Physiological (descriptive)	Loudness units
Sound level	Instrument measurement	Decibels

The first four quantities listed are physical quantities; that is, they have no dependence whatever

on the characteristics of the human ear.[1] The next two quantities are physiological quantities and are related to the performance of an average ear.[2][3] The last quantity is an instrument measurement as obtained on the sound-level meter.[4]

Sound Intensity

Sound intensity is a purely physical quantity which is measured in watts per square centimeter. If a point source of sound is located in space at point A, a sound wave, spherical about the point, is radiated into space. The total power being radiated from an imaginary sphere at a distance D from the source is, of course, still the same as the power of the source. The intensity at any point on this sphere, however, is expressed as the watts flowing through a square-centimeter area at that point and is obtained by dividing the total power of the source by the area of the sphere.

Sound-intensity Level

Sound-intensity level is the same as sound intensity, except for the unit which is decibels instead of watts per square centimeter. The decibel scale is a logarithmic scale and indicates the level above or below a standard reference level, which reference must always be expressed or understood if the decibel reading is to be transferred into absolute units of intensity. For sound, the zero-reference level for the decibel scale is 10^{-16} watts per square centimeter. This is approximately the minimum audible 1000-cycle intensity. The characteristics of the decibel scale are such that each increase of 10 decibels in level represents an intensity increase of tenfold in absolute value, as shown in **Fig. 1**. A sound, whose intensity is I (watts per square centimeter), has an

$$\text{intensity level} = 10 \log_{10} \frac{I}{10^{-16}}, \text{ decibels.}$$

Sound Pressure

Sound pressure at a point in space is expressed in dynes per square centimeter and it represents the small pressure pulsations above and below atmospheric pressure produced by the flow of sound energy past that point. Sound intensity and sound pressure are terms analogous to the electrical terms power and voltage. In the electrical system, power is proportional to the square of the voltage; similarly in the sound system, sound intensity is proportional to the square of the pressure.

This relation applies only when the sound wave is a spherical or a plane wave, such as radiated from a point source in a free field. It does not apply in cases where sound is being radiated from multiple points or where there are a series of multiple reflections or standing-wave patterns produced by reflections from nearby walls and other objects. In such cases, power depends not only upon the pressure but also upon the particle velocity of the air and the phase relationships which exist between the pressure and the velocity of the individual frequency components in the wave.

Sound-pressure Level

As in the case of intensity level and intensity, sound-pressure level is merely a logarithmic way of expressing sound pressure. The reference level of the logarithmic decibel pressure scale is 0.000204 dynes per square centimeter, root-mean-square. For a free field, that is a plane or spherical wavefront, in dry air at 20 C and 760 millimeters pressure, this reference pressure is required to produce the reference intensity described. It has already been shown that each 10-decibel increase in intensity level produces a tenfold increase in intensity. However, since intensity is proportional to the square of the pressure, a 20-decibel increase in sound-pressure level is required to produce a tenfold increase in sound pressure, as can be seen from **Fig. 1**. A sound whose pressure is P dynes per square centimeter, root-mean-square, has a

$$\text{pressure level} = 20 \log_{10} \frac{P}{0.000204}, \text{ decibels.}$$

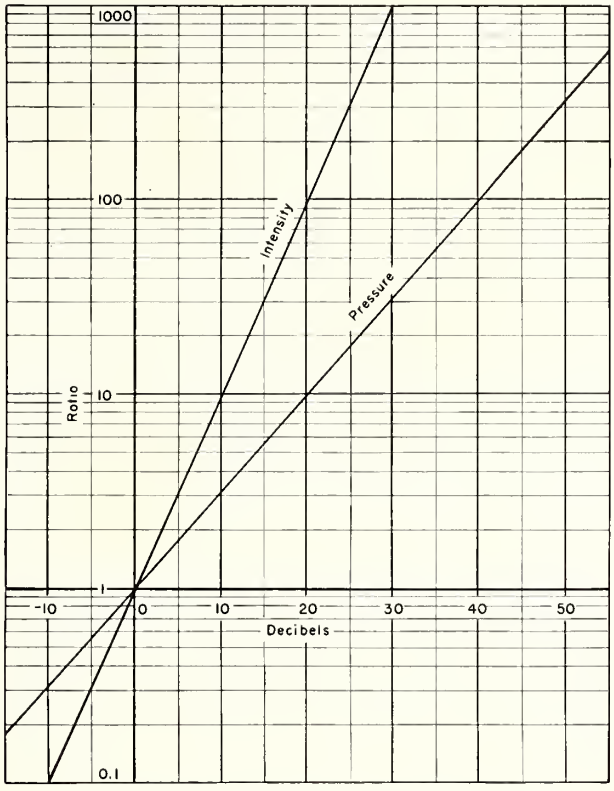


Fig. 1. Illustrating the relation between sound pressure and sound intensity

Loudness Level

It is well known that the human ear has a limited frequency-response range. It reponds better to some frequencies than to others. This means that two unlike frequencies which are adjusted to the same loudness may have entirely different intensities.

(1) American Stds. Association, Std. Z24.1, "Acoustical Terminology."
(2) "Loudness—its Definition, Measurement, and Calculation," by Harvey Fletcher and W. A. Munson, *Journ. of the Acoust. Soc. of Am.*, vol. 5, p. 82, October 1933.
(3) American Stds. Association, Std. Z24.2, "Noise Measurement."
(4) American Stds. Association, Std. Z24.3, "Sound-Level Meters."

The amount by which the intensity levels of any two frequencies must differ in order to appear equally loud is shown by the curves in **Fig. 2**. Each curve represents a contour of equal loudness. Each point for the bottom curve or the threshold-of-hearing curve was obtained by adjusting the intensity level of each frequency in question until it was just audible to a good ear. These intensity levels were then plotted on the curve. The next curve was started at 1000 cycles on a level 10 decibels higher. Now other frequencies were varied in intensity until they sounded as loud as the 1000-cycle reference tone to an average ear and their intensity levels plotted.

The remaining curves were obtained in a similar manner, with each curve started at 1000 cycles per second at a level 10 decibels higher than the previous curve. The top curve represents the threshold of feeling or the level at which sound becomes physically painful. Each curve has a specific loudness level assigned to it which is measured in phons and the values appear above the 1000-cycle point in **Fig. 2**. It is to be noted that because of the way in which these curves were obtained, intensity level and loudness level are numerically equal at 1000 cycles only.

Loudness

When the loudness levels of two tones are given, it is obvious which of the two is the louder, but no means has yet been indicated for describing the physiological difference produced upon the observer. Therefore a loudness scale has been devised and related to loudness level. It is shown in **Fig. 3**.

Loudness is expressed in loudness units and the scale selected is such that a two-to-one change in loudness units produces a two-to-one change in loudness as judged by the observer. It was arbitrarily decided that a loudness of 100,000 units would represent a loudness level of 100 phons. This established one point on the curve. With this point as a reference, the loudness level corresponding to 50,000 loudness units was determined, by observer judgment, by varying the level of the 1000-cycle tone until the observer judged the loudness to be half as great as the reference. The other points were obtained in a similar manner, starting with the second point just derived as the reference loudness. This curve is not used to any great extent in industry, but it serves to indicate to the uninitiated practitioner the difference in loudness level required to produce a two-to-one change in loudness. By examining the curve, it can be seen that in the higher level range, a change of approximately 10 phons is required to produce a two-to-one change in loudness. This curve was obtained with a 1000-cycle tone but it applies to all frequencies because the loudness of any frequency along a loudness-level contour is equal to the 1000-cycle loudness.

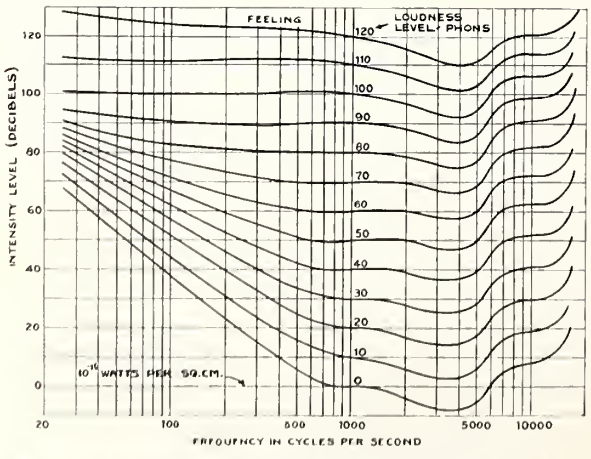


Fig. 2. Constant-loudness contours from the threshold of hearing to the threshold of feeling

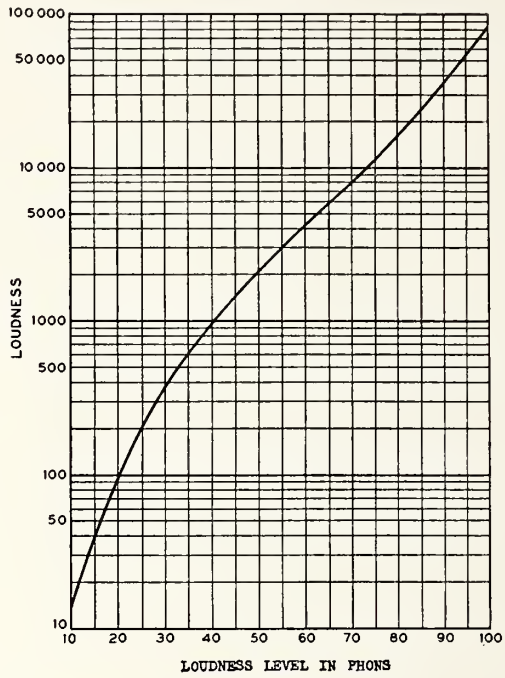


Fig. 3. Relation between loudness and loudness level

Sound Level

Sound level is an instrument reading obtained on the sound-level meter. Although it is desirable to have the sound-level meter simulate the human ear in its frequency-response characteristic, for practical reasons of instrument design, the simulation is only approximate. If the simulation were perfect, a sound-level meter would read loudness level in phons. However because it is only approximate, another term, sound level, is used to describe the instrument reading and it is expressed in decibels.

As shown in **Fig. 2**, the response curve of the ear is not constant but varies with level. To operate ideally, the sound-level meter should have many responses to correspond. This, however, would result in an unnecessarily complicated and impractical instrument. So it was decided to compromise and include only three definite frequency responses selected from the many shown. The three selected are approximations to the 40-phon loudness-level contour, the 70-phon loudness-level contour, and the 100-phon or "flat" loudness-level contour, the latter being approximated by a flat response characteristic.

SOUND-LEVEL METER

The sound-level meter is shown in **Fig. 4**. It consists essentially of a microphone actuated by sound pressure, an amplifier to amplify the voltages generated by the microphone, and an indicating instrument to read the magnitude of the applied signal.[5] A range selector can be varied in 10-decibel steps to cover the range from 20 to 120 decibels. The network selector is a 3-position switch for selecting any one of the three ear-weighting networks described in the previous section. To read sound level in decibels, it is merely necessary to add the indication of the range selector to the deflection of the indicating instrument. When the flat-response network is used, a sound-level meter also measures sound-pressure level in any kind of sound field, and measures sound-intensity level only in special cases.*

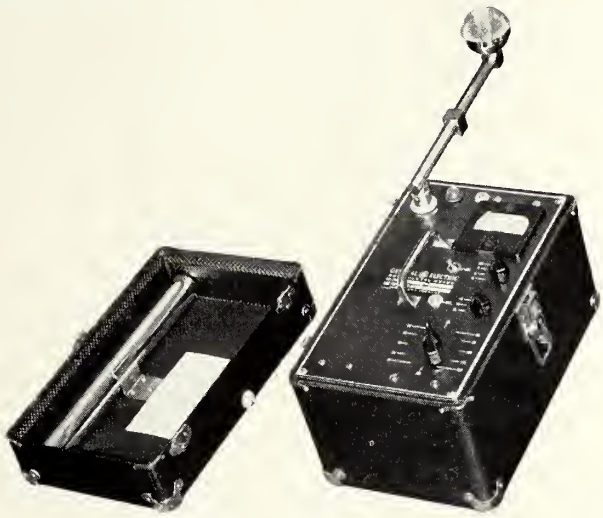


Fig. 4. The portable sound-level meter with cover removed

A voltage-checking switch permits checking the voltages of the A, B, and C batteries used in the amplifier. A red mark on the scale indicates the point at which batteries must be replaced. The microphone of the sound-level meter is mounted on an extension arm which is turned away from the case when in use to a position far enough out to minimize obstacle effects and reflections from the case of the amplifier. Provision has been made for attaching an extension cable and tripod to the microphone. The complete sound-level meter, including the calibrator, is contained in a case of over-all dimensions 7¾ by 9¼ by 12¾ inches and weighs but 20 pounds.

Calibration

An important part of any sound-level meter is its calibrating unit. Because the sensitivity of the instrument varies with temperature, age, battery voltage, tube condition, microphone condition, and circuit constants throughout the amplifier, a calibrator is essential to insure correct over-all amplification, at all times. The standard method generally used, which consists of applying a known voltage to the amplifier and adjusting the gain of the amplifier only, is not satisfactory because it does not include a check of the microphone.

This objection has been overcome in the instrument under consideration by the use of an acoustic calibrator to generate a standard sound which is applied through the microphone. The calibrating unit is a single-frequency sound source which can be blown by mouth or by compressed air. Its characteristic is such that it will not produce a sound if blown too hard or not hard enough. By applying the proper intermediate pressure and varying this slightly until a maximum deflection is reached, the sound-level meter can be calibrated in accordance with the output designated on the calibrator. If the instrument does not read properly, the sensitivity adjustment is varied until the reading is correct.

Each sound-level meter is carefully tested and adjusted, and individually calibrated to insure utmost accuracy in the finished product. In spite of the fact that the American Standards Association allows plus or minus three decibels variation in readings between sound-level meters for sounds below 1000 cycles, the many sound-level meters in use in the General Electric Company have indicated agreement to plus or minus one decibel consistently when checked periodically against the laboratory standard. This high order of accuracy is attributed to the special care and individual attention given each instrument and also to the improved calibrating means used, which makes it possible to detect immediately an inaccuracy in operation of either the amplifier, the microphone, or the indicating instrument. When the sound-level meter is used with the portable wave analyzer, shown in **Fig. 5**, detailed analysis can be made of the individual frequency components and the magnitude of each can be determined quickly and accurately.

SOUND-MEASURING TECHNIQUE

The methods of measuring sound in practice and the precautions to be observed will be described briefly in the following section.[6]

(5) "An Improved Sound-Level Meter," by W. Mikelson, GENERAL ELECTRIC REVIEW, vol. 43, p. 515, December 1940.

*With the flat-response setting the instrument also reads intensity level but only in a plane or spherical sound wave such as radiated from a point source in a free field. To obtain intensity level under any other condition, it is necessary to measure pressure, particle velocity and their phase for each frequency component present, and this process becomes rather involved, requiring laboratory technique.

(6) "AIEE Test Code for Apparatus Noise Measurement," *AIEE Journal*, March 1939.

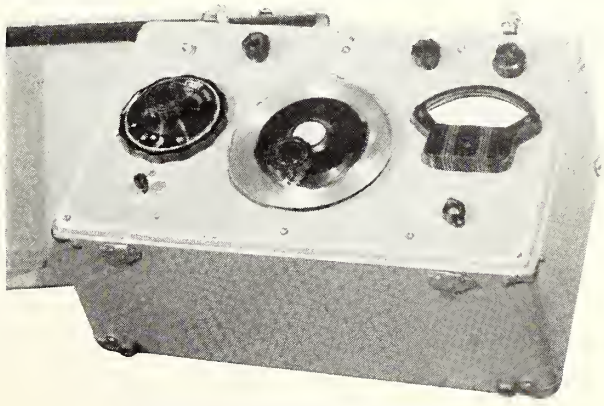


Fig. 5. The portable wave analyzer

Locations for Setup

For best results, sound measurements should be made in locations where sound reflections from nearby objects, and standing-wave patterns will produce the smallest effect on the sound actually being radiated from the apparatus being measured. The ideal location would be in free space, for both the apparatus and the sound-level meter. Actually most measurements are made with the apparatus near the ground. Hence it is desirable to have the ground surface as absorbent to sound as possible to minimize this reflection. In practice, most measurements are also made in localities where walls or other objects are in the immediate vicinity. These walls and objects should likewise be lined with sound-absorbent material to minimize reflections and these surfaces should be kept as far away from the source and measuring equipment as possible.

In general, if all nearby surfaces are treated to be sound absorbent, it is desirable to have these surfaces

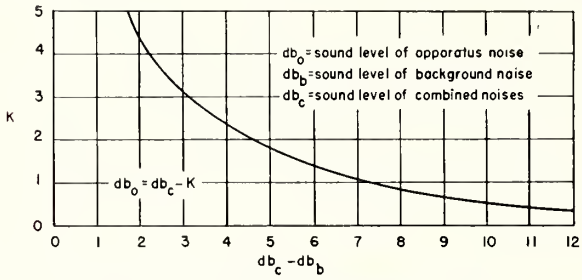


Fig. 6. Correction curve for background noise

at least as far from the apparatus and the microphone as the distance between these equipments. If the surfaces are untreated they should be farther from the apparatus.

Correction for Background

If the background level in which the readings are taken is at least 10 decibels below the level with the apparatus running, no correction need be applied for the background. If the difference is less, a correction should be applied which can be obtained from the curve in Fig. 6.

Soundproof Room

If the background noise is too high to read the apparatus noise, it is necessary to resort to a completely enclosed soundproof booth to attenuate the background noise below the level of the apparatus to be measured. Soundproof room construction usually consists of a heavy masonry enclosure (including separate floor) well jointed and sealed so that it is reasonably airtight, to attenuate and prevent the transmission of sound through the walls. Interior surfaces are covered with a sound-absorbent lining to minimize reflections and simulate free field conditions as closely as possible. With a well-constructed room of this type and a heavy well-sealed door, it is possible to attenuate the outside noise about 40 decibels.

If the floor on which the structure is placed is subject to considerable vibration, this can be transmitted through the room structure and result in noise inside the room, reducing the effectiveness of the room considerably. In such cases it is necessary to resort to vibration-isolating treatments consisting of spring-and-rubber supports for the floor of the enclosure. It is possible to provide ventilation if the air ducts are made of heavy masonry like the room, and lined and honey-combed inside with sound-absorbent material to produce a series of long sound-absorbing passages.[7]

Selection of Weighting Network

There are no stringent rules on the selection of the proper ear-weighting network although it is customary to use the "40" network for sounds up to 60; the "70" network for sounds from 50 to 90; and the "flat" network from 80 up. The network is selected on the basis of the level expected at the ear of the nearest observer. For example, a machine which measures 100 at three feet may measure 45 at the point where it will be heard when installed, therefore, the "40" network is used. Most of the measurements made on our apparatus have been made on the "40" network.

Microphone Technique

It is generally desirable to make the measurement as close to the apparatus as possible. On small apparatus such as fractional-horsepower motors, a distance of one foot is considered satisfactory. On larger apparatus a distance of three feet is usually used. When measurements are made indoors, it is seldom desirable to make measurements at distances greater than five feet, because reflections will begin to introduce errors. If the measurement is made outside, however, this distance may be increased to any desirable value. This is generally done only on equipment which is to be used outside, however. For apparatus intended for inside use, such as turbine generators, the three- to five-foot distance should be used.

Because the various parts and surfaces of a machine can be vibrating at different frequencies, intensities, or phases, measurements taken at different points around the machine can differ considerably. For this reason, several readings are taken around the unit spaced three to five feet apart. Standing-wave patterns can also be produced near large machinery, not only from reflections from nearby obstacles but also from interferences set up by various parts and surfaces vibrating in different phases. It is often possible to detect differences of reading of as much as 10 decibels by moving the microphone a distance of only six inches. In such cases, most reliable results can be obtained by moving the microphone within a circle of six-inch radius and mentally averaging the readings observed on the indicating instrument.

(7) "Aphonic Room of the General Electric Research Laboratory," by K. D. McMahan, General Electric Review, vol. 41, p. 523, December, 1938.

DECIBEL-SCALE CHARACTERISTICS

A general description of the quantitative characteristics of the decibel scale has been given in **Fig. 1** and also in the description of the quantity sound-intensity level. The sound levels of several typical locations are listed below.

Residences	25– 50
Offices	40– 75
Factories	60–100
Normal speech at 3 ft	60
Noisy restaurant, stenographic room, average factory	75

Other characteristics of the scale which are not obvious to the user from the above description will be given here.

Physiological Effects

It is approximately true that one decibel is the smallest difference in intensity detectable to the ear, and this difference can usually be detected only under ideal listening conditions. Two decibels are more easily detectable, and three decibels are enough to be considered as a definitely desirable sound reduction provided the cost to obtain this reduction is not exorbitant. A six-decibel sound reduction is considered very good and 10 or more is exceptional. From the previous section on Loudness, it can be deduced that a change in sound level of 10 decibels constitutes approximately a two-to-one change in loudness, and from **Fig. 1** it is seen that a 10-decibel change corresponds to a tenfold increase in intensity or acoustic power. This means that it takes 10 motors of equal sound level running together to produce a sound which is twice as loud as that from one motor in spite of the fact that the acoustic power is 10 times greater.

Adding Decibels

Sound levels cannot be added arithmetically. For example, if 10 motors, each of which had a level of 80 decibels, were sounded together, the total level would be but 10 decibels greater than that of any single motor, or 90 decibels. Or if two equal motors are sounded together, the increase in level will be three decibels.

An important consideration in the solution of sound problems is that of the addition of unequal sound levels. If, for example, two similar sounds differ from each other by 10 decibels, such as 60 and 70 decibels, the total level when both are sounded together is but one-half decibel more than the louder, or 70.5 decibels. This means that the complete elimination of the 60-decibel sound will reduce the total level only one-half decibel, which difference is not significant to the human ear. If the sounds are dissimilar and have different frequency characteristics, the levels will still add as described above, but now the ear will notice the absence of the 60-decibel sound if it is eliminated because of the resultant difference in quality or frequency composition of the sound. The manner in which sounds of different intensity levels add when sounded together is indicated in **Fig. 7.**

CONCLUSION

An attempt has been made in this article to explain the terminology used in sound-measurement work and to give a practical description of the apparatus and

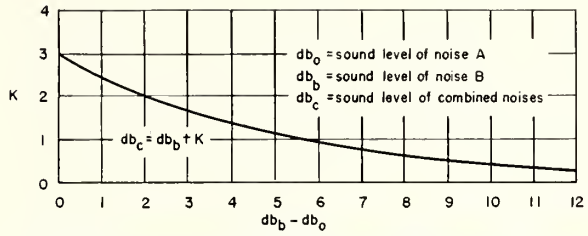

4
3
2
1
0
K
db_o = sound level of noise A
db_b = sound level of noise B
db_c = sound level of combined noises
$db_c = db_b + K$
0 1 2 3 4 5 6 7 8 9 10 11 12
$db_b - db_o$

Fig. 7. Showing the manner in which sounds of different intensity levels add when sounded together

methods used in the measurement of sound and in the interpretation of the results obtained. As stated at the beginning, this covers the measurement of total sound only and not the analysis of sound nor the measurement and analysis of vibration. To break the sound or vibration into its various frequency components and determine their respective intensities so that the sound can be tracked to its source more easily, it is necessary to resort to analysis using a wave analyzer. Considerable useful information can be obtained, however, with total sound measurements only. Sound-level meters can be used advantageously for many applications including the study and control of noise in private and public buildings, the study and control of noise in machinery, and quality control and inspection problems in factory production.

VIBRATION TESTING . . .

Vibration meters to measure oscillating stresses in apparatus

Vibration motors to produce oscillations for testing purposes

By Dr. R.O. FEHR
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Robert Fehr

IN the majority of cases breakage in machine structure is caused by oscillating stresses rather than static stresses. For example, failures due to fatigue in a material result from oscillating stresses; also, damage done to buildings is caused most often by vibratory forces. In the latter instance cracks in walls

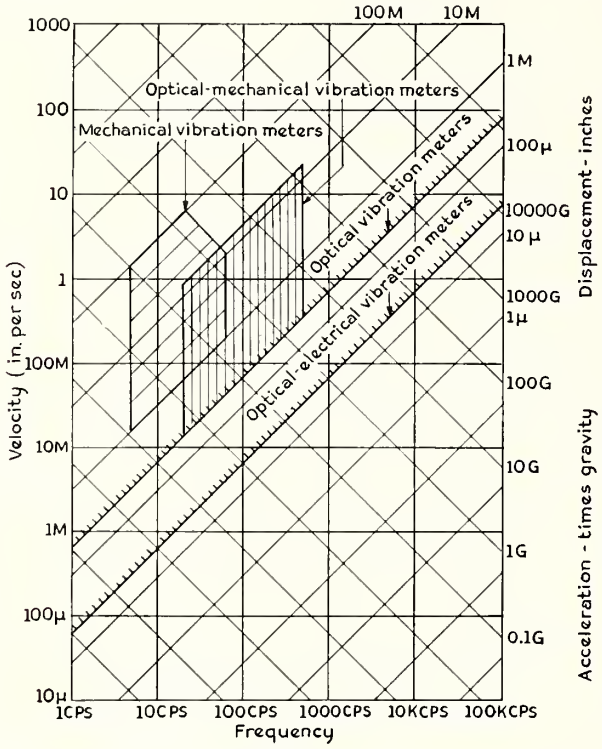

Fig. 1(*a*). Vibration ranges of mechanical and optical vibration meters

and in floors are very frequently caused by vibrations in those structures.

A person's working efficiency often is reduced by the noise produced by vibrating machines and buildings. The elimination, or at least reduction, and confinement of vibrations are, therefore, important engineering problems.

In most cases vibration is not desirable. However, there are certain purposes for which the generation of vibration is necessary. Examples of this would be vibrations used for the inspection of materials and structures, and ultrasonic vibrations as applied in the field of biochemistry.

To help solve these problems, various kinds of apparatus are available for the measurement of vibration displacement, velocity, acceleration (vibration meters), and for the generation of vibrations (vibration motors).

Vibration motors can duplicate the oscillating stresses to which materials and apparatus are subjected under actual operating conditions. Thus, they make it possible to study the vibration characteristics of those materials and apparatus. In addition they are helpful in the calibration of vibration meters.

It is the object of this article to describe the most commonly used vibration meters and vibration motors from the standpoint of ranges, advantages and disadvantages, and their application to the more important problems in the field of vibration engineering.

Specifications

Vibration meters and vibration motors must meet certain specifications if they are to be applied most advantageously.

Vibration Meters. Vibration meters should meet specifications regarding sensitivity which, in the case of electrical instruments (consisting in general of a detector unit and an amplifier unit), should be high enough so that the effect of stray electrical interference on the cable connecting the detector and the remainder of the circuit is negligible. Other specifications are concerned with such physical properties as weight and size, provisions for mounting the instrument to the vibrating object, and the possibility of recording the measurement by means of oscillograph or recorder.

Vibration Motors. These motors are specified mainly by the maximum displacement (or velocity, or acceleration) versus frequency which can be obtained under various mechanical loads, the maximum force which the moving element of the vibration motor can transmit, the physical dimensions, and the facilities for attachment of the objects to be vibrated. In case of electric vibration motors, it is preferable for the driving-point impedance* of the motor to be matched, under all load conditions, by the output impedance of the power supply.

*The driving-point impedance is the ratio of the applied potential difference to the resultant current at the terminals of the vibration motor.

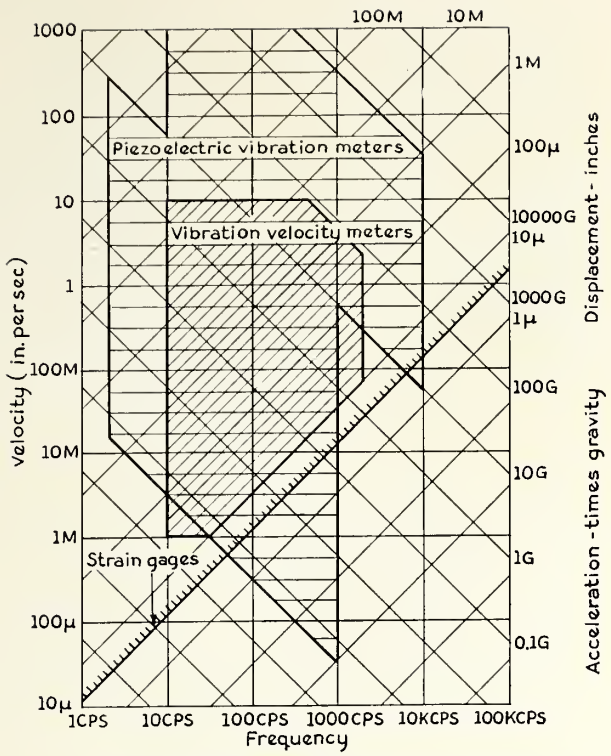

Fig. 1(*b*). Vibration ranges of electrical vibration meters

Available Vibration Meters

Vibration meters provide a magnified indication of the vibratory motion. The meters indicate either displacement, velocity, or acceleration. Depending on the means used for this magnification in a particular meter, the magnification of the vibratory motion is obtained by the application of either mechanical, optical, or electrical principles, or by a combination of several of them.

There are various mechanical, optical, and electrical systems that can be utilized for the design of vibration meters. This results in a large number of available designs for these meters, each of which covers certain ranges, and has certain advantages and disadvantages. The characteristics of some of the more useful designs are given in the following paragraphs, while the approximate limits of their ranges are shown in **Figs. 1(*a*)** and **1(*b*)**.

Mechanical Magnification

One of the most commonly used design principles is mechanical magnification. The displacement caused by the vibration is magnified by either a system of levers or by a train of gears. The readings obtained are, in most cases, proportional to displacement.

The advantages of these instruments are their relatively low cost, light weight, and usefulness in the hands of those having little experience in vibration work. Their disadvantages are: low sensitivity, limited frequency range, and limited acceleration range (**Fig. 1(*a*)**). A typical vibration meter utilizing mechanical amplification is shown in **Fig. 2**.

These instruments are very useful in the factory for vibration measurements on low- and medium-speed machines, where very accurate vibration readings are not required.

Optical-Mechanical Magnification

A second type of instrument uses optical-mechanical principles for the magnification. The displacement of the vibration is magnified first mechanically, then optically. For example, a mirror is moved mechanically by the vibration, and a light beam is reflected from the mirror upon a glass screen, the width of the light beam on the screen indicating the vibration displacement. This type of meter is shown in **Fig. 3**.

These instruments have a higher sensitivity than the instruments using pure mechanical means for obtaining magnification. Their frequency and acceleration ranges are much higher, (as can be seen from **Fig. 1(*a*)**). However, their cost tends to be higher, and they are not as compact and sturdy in design as the previously mentioned type of instrument.

They are useful in the factory for accurate measurement on rotating machinery of most speed ranges. They are also very helpful in vibration-laboratory work, if they are used within the limitations of their ranges (**Fig. 1(*a*)**).

Optical Magnification

This classification includes microscopes and instruments working on interferometer principles. They are usually very accurate, and they have wide frequency and displacement ranges. These instruments are generally placed in a special, permanent mounting. The setup of these instruments is rather delicate, and they

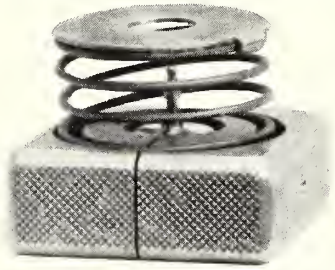

Fig. 2. Dial gage—mechanical vibration meter (side and bottom view)

Fig. 3. Lightbeam vibration-displacement indicator—mechanical-optical vibration meter

can be used to best advantage by men trained for vibration work. Instruments working on this prineiple are used almost exclusively in the laboratory as primary vibration standards, for the ealibration of vibration meters, etc. (Their ranges are also shown in **Fig. 1(*a*)**.)

Optical-Electrical Magnification

Some vibration meters use a combination of electrieal and optical prineiples for magnifying the vibration. A light beam, which is controlled by the motion of the vibrating object, is direeted on a photocell. The output of the photoeell is electrically magnified.

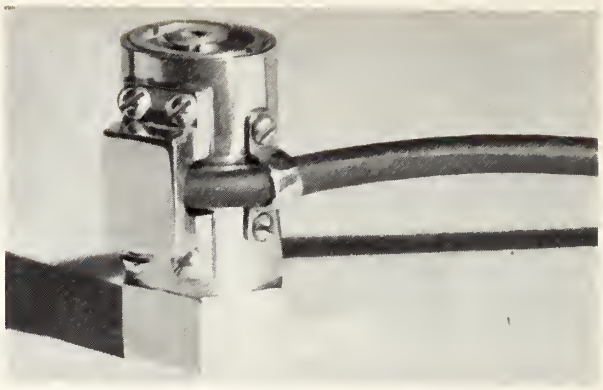

Fig. 5. Quartz-crystal accelerometer—electrical vibration meter

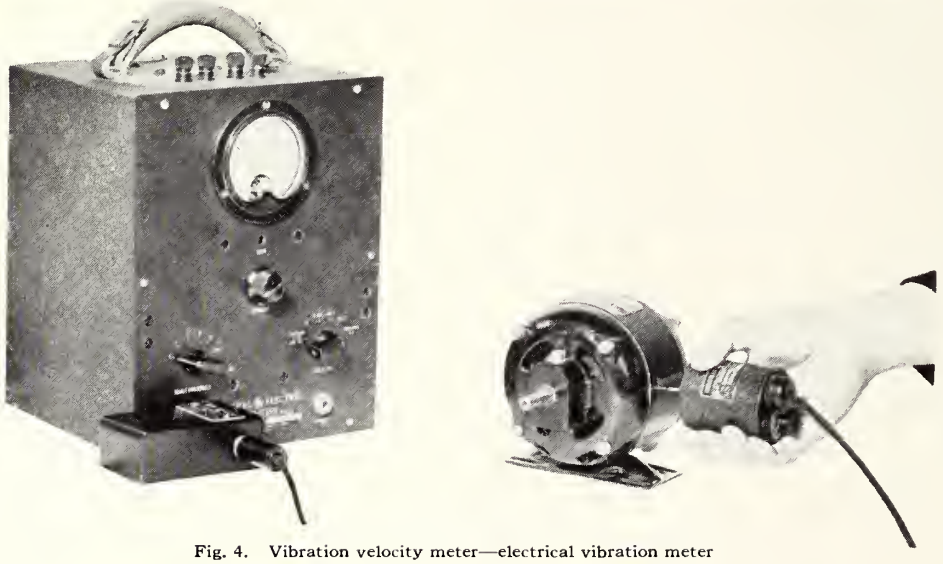

Fig. 4. Vibration velocity meter—electrical vibration meter

Vibration meters working on this prineiple have very wide displaeement and frequeney ranges. They are not portable, and they are, in general, a part of an apparatus, the vibration of which has to be measured. A speeial setup is required. These meters are used almost exclusively in the laboratory for measurement of very small displaeements (**Fig. 1(*a*)**), or as part of material testing maehines.

Electrical Magnification

The design of many vibration meters utilizes electrieal prineiples for the magnifieation of the vibratory motion. The most eommon eleetrieal prineiples, on whieh the magnification is based, are: the induetion of voltage in a eoil which moves in the airgap of a permanent magnet, the piezoelectric effect, or the change of resistanee in a wire due to its elongation or compression.

These instruments are, in general, portable. They cover rather wide displacement and frequency ranges, and some training is required to operate them satisfactorily. The reading can be made to indieate displacement, velocity, or acceleration depending on the use of electric differentiation or integration.

Meters working on this principle consist, in general, of a detector unit, an amplifier unit, and an indicating unit. The wave-train of the vibration ean be made visible by an oseillograph, and it ean be reeorded on photographie film. The peak value (varying with time) of a sinusoidal vibration ean be reeorded by a voltage-sensitive reeorder.

These meters are used in the laboratory as well as in the factory where accurate measurements are required, or where the vibration is outside the range of vibration meters working with mechanieal, or optical-meehanieal magnification. They are also useful where the operator cannot be located close to the vibrating objeet for reasons of temperature or safety. Meters using the prineiple of a eoil moving in the airgap of a permanent magnet (vibration-veloeity meters), shown in **Fig. 4**, and meters utilizing the piezoelectric effects, one of which is shown in **Fig. 5**, are commonly used for the purposes just mentioned. In the instrument working on the piezoeleetrie effect the deteetor has a high output impedanee whieh results in a greater suseeptibility of the meter toward electrical interferences.

Meters using the change of resistanee of a wire are frequently used for vibration measurements because of their extremely light weight, small size, and low cost. Instruments operating on this prineiple are useful for indicating the strain at the surface of the vibrating

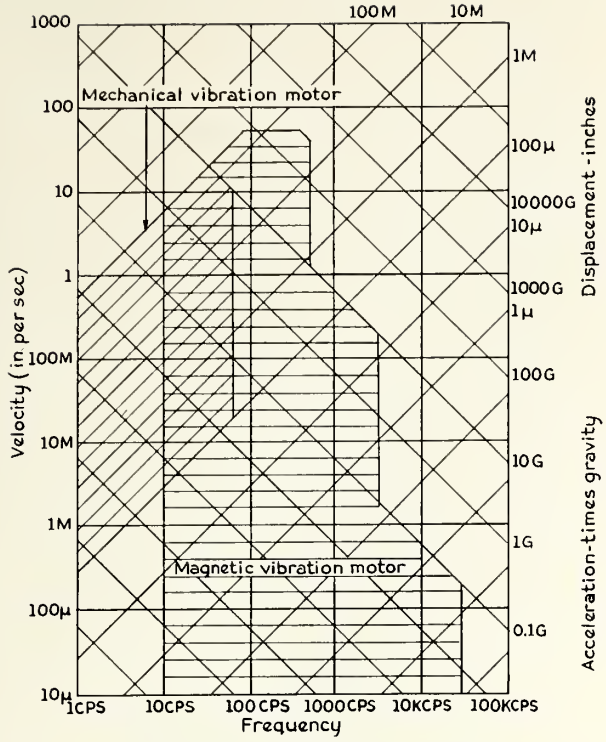

Fig. 6. Vibration ranges of vibration motors

object, particularly in applications where only very small additional weight can be tolerated.The mode of vibration has to be known to interpret the strain measurements into displacement values. (The ranges of different electric meters are shown in **Fig. 1(*b*)**.)

Available Vibration Motors

Vibration motors exert a vibratory force on the structures to be vibrated. In most cases this vibratory force is transmitted either by mechanical means or by magnetic effects. These forces act either on a moving element which is a part of the vibration motor, and which has mounting provisions for the object to be tested, or directly on the object to be vibrated. There are other types of vibration motors available; however, the description to be given here will be restricted to those mentioned, since these two types of motors are the most widely used. The ranges of these vibration motors are shown in **Fig. 6**.

Mechanical Means

Vibration motors, using mechanical means for the transmission of the force, generally work in one of the following two ways. A platform, the motion of which is restricted in all but one or two directions, is moved back and forth by a connecting rod attached eccentrically to the shaft of an electric motor. Another design uses two unbalanced motors which are rigidly attached to a platform mounted on a flexible rubber base. The apparatus to be vibrated is mounted on the platform.

Vibration motors using mechanical means for the transmission of the force can be made very powerful, and they can be built to vibrate rather large loads. However, they are used only for low-frequency vibration. They are easy to operate and when well designed do not require much service. They are applied for vibration testing of apparatus which is to be subjected to vibrations when in service. (Their ranges are shown in **Fig. 6**.)

Magnetic Effects

There are several types of motors available which use magnetic effects to transmit the vibratory force.

One type has an a-c coil, moving in the airgap of an electromagnet, to which the test pieces can be mounted, as shown in **Fig. 7**. A platform is attached to the coil structure for mounting purposes.

Another type uses an iron structure as the armature of an electromagnet. The test samples are attached to this iron structure. Very high displacement can be obtained when the iron structure is vibrated at its resonance, especially when suspended at its nodal points. In some cases the electromagnet can be applied directly to the structure to be tested which in this case serves as an armature for the coils. (Their ranges are shown in **Fig. 6**.)

The vibration motors utilizing the magnetic effect require a power source of variable frequency as, for

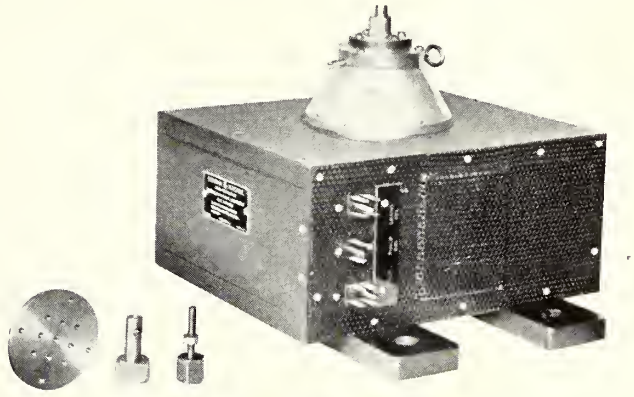

Fig. 7. Magnetic vibration motor

Fig. 8. Power supply (1000 va) for vibration motor

example, the one shown in **Fig. 8**. They are not as simple to operate as the vibration motors using meehanical means for the transmission of the foree. Their frequeney range is rather large, and large aeeelerations ean be obtained by using a resonating iron strueture as the armature of an eleetromagnet.

The applieations of vibration motors using magnetie effects inelude ealibration of vibration instruments, fatigue testing, and determination of natural frequeneies of struetures.

Source of Data

The limitations for the vibration meters given in **Figs. 1(*a*)** and **1(*b*)** were based on ranges of vibration displacement, vibration veloeity, and vibration aeeeleration in whieh the different types of vibration meters have been successfully applied by the author. The boundaries of the ranges of the vibration motors in **Fig. 6** were based on the limitations of the most eommon types of vibration motors known to the author. It is, therefore, possible that the mentioned types of vibration meters and vibration motors may sometimes be found to be applied in a range which extends beyond the boundaries given in the diagrams **Figs. 1(*a*)**, **1(*b*)**, and **6**.

PRODUCTION TESTING . . .

The use of cathode-ray tubes and light-beam galvanometers to speed the testing of mass-produced electrical products

By C. M. SUMMERS
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Claude M Summers

IN THE manufacture of a large-production item (such as a radio transformer or receiver, a fractional-horsepower motor or the armature of a universal motor, where several thousand units may be produced per week), the time required to electrically check the quality of the product may vary from a few seconds to several minutes. This time may appear to be insignificant in the total time required to produce the article. In more than one instance, however, ten per cent of the total testing time is required for the voltmeter or ammeter to come to rest so that a reading can be taken.

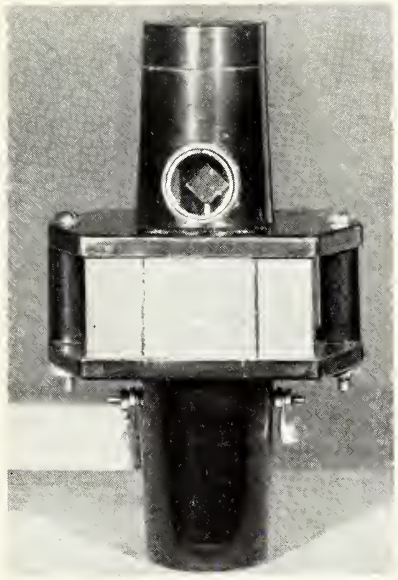

Fig. 1. The portable light-beam galvanometer used in production measurements

Furthermore, many types of electrical tests do not require a high degree of accuracy, and it is questionable whether the use of a high-grade instrument with an accuracy of less than 0.5 per cent is warranted on a test where a simple indicator is adequate. In order to facilitate testing procedures for large quantity production, several test devices have been devised which employ light-beam galvanometers or cathode-ray tubes as visual indicators.

Inductance Bridge

A good example of a test equipment in which a precision instrument was not required was a certain inductance bridge where the voltage across one part of a circuit was adjusted to equal the voltage across a second part. This setup required a particular type of vacuum-tube voltmeter, and in the past a delicate microammeter was used in the vacuum-tube-voltmeter circuit. These meters are relatively expensive and not readily available. Therefore, in a recent expansion of this type of test equipment, a portable-type galvanometer supplied by a thermocouple was used. The galvanometers are suitable for factory use, for they will stand as much abuse as the microammeter while their maintenance is less. The operating time saved is not appreciable but a high-precision instrument is not utilized where only quantitative measurements are required.

Impedance Bridge

The ballasts for fluorescent lighting present a problem in production measurements because rapid tests with close limits have to be maintained. In a typical case the current through the reactor had to be held between 0.270–0.330 amp. Thus the operator had to closely observe the reading of the meter, and the meter had to be maintained in good calibration. A new type of impedance bridge was constructed which employed a portable-type light-beam galvanometer with zero at the center of the scale for the detector. The limits were indicated by the deflection of a light beam, to the right or left of center, for a distance of an inch or more. This is a good example of a production test accomplished in a shorter time, just as accurately, with a cheaper visual indicator.

The galvanometer used is a portable type. It has been used for more than a year on a dynamic balancing machine with practically no maintenance. Thus, the light-beam galvanometer, shown in **Fig. 1**, is playing an important part in high-speed production measurements where a visual indication is adequate and consistent with production circumstances.

High-potential Testing

The cathode-ray tube is well suited for an instantaneous indicator. One simple application of the cathode-ray tube to a factory test is in connection with high-potential testing to ground. The circuit diagram is shown in **Fig. 2**. A sinusoidal sweep circuit with a phase-angle and amplitude adjustment permits the open-circuit voltage of the high-potential

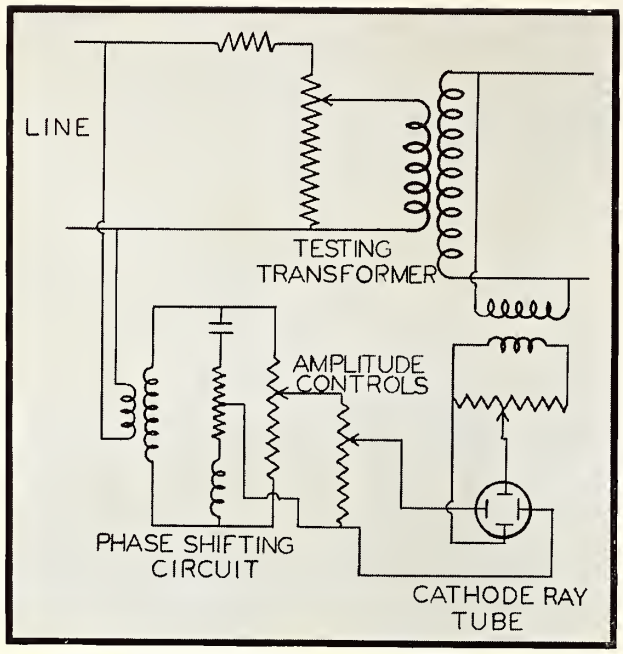

Fig. 2. Circuit of the testing transformer and cathode-ray-tube fault indicator

testing transformer to be adjusted to a circle, or some other desirable image. If the high-potential-transformer circuit has any appreciable impedance, its voltage will shift in phase and magnitude relative to its open-circuit value, depending on the nature of the load applied. For example, if the dielectric of the device under test is damp, so that it has a low value of resistance, the magnitude of the test voltage will drop slightly without an appreciable shift in phase. The image on the screen will then appear as an ellipse with its major axis horizontal, as shown at *A* in **Fig. 3**. If the dielectric circuit contains a low capacitive reactance, the phase angle of the test voltage will shift to position shown at *B*. If intense corona or sparks are jumping around or through the insulation, the image appears as in *D* while the image of a short circuit to ground collapses to a horizontal line. Thus the operator has a continuous visual picture of the conditions of the dielectric as well as the waveform of the test voltage, or any surges appearing on it.

Armature Testing

Another interesting problem is involved in the testing of small armatures for d-c or universal motors, such as those used in vacuum sweepers, or food mixers. In some cases there may be 50 or more bars on a commutator $\frac{3}{4}$ in. in diameter, hence the bar has a width of less than $\frac{1}{16}$ in. It is desirable and often essential to test the winding between each adjacent pair of bars for the number of turns, short circuit, open circuit, and proper lead connections. In order to produce 5000 a week, an armature would have to pass through this test at the rate of one every two minutes, twenty-four hours per day, and seven days a week. A manual test is very tiresome, slow, and inaccurate. In this case a more elaborate instantaneous semiautomatic test is justified and the cathode-ray tube served a useful purpose in this equipment.

The block diagram of the armature tester is shown in **Fig. 4**. The essential elements of the circuit and their function are as follows:

The armature, *A*, with a pair of brushes adjusted to make contact with adjacent commutator bars, is rotated in a magnetic field, *B*, supplied by a 1000-cycle generator. A standard source of voltage, *C*, has a phase-shifting and an amplitude-control circuit so that its voltage can be made equal in magnitude and opposite in phase to that generated in a normal winding of the armature. Any difference between these two voltages is fed into a two-stage amplifier, *D* and *E*, with a 1000-cycle low-pass filter, *F*, between stages. The output of the amplifier is placed on one pair of plates of the cathode-ray tube, *G*. Another filter, *H*, is placed between the 1000-cycle line and the second pair of plates of the cathode-ray tube.

When the fundamental of the voltage generated in the armature coil is exactly equal and opposite to the standard voltage, the image on the cathode-ray screen is a horizontal line. If the armature voltage is too high, the image may be made to appear as an elliptical figure in the first and third quadrants of the cathode-ray tube by adjusting the phase position of the sweep voltage with respect to the output voltage of the amplifier. If the armature voltage is too low, the image will appear in the second and fourth quadrants. A short circuit has another characteristic image, while improper lead connections will be represented by still another individual image. Thus, by the nature of the image, the operator can determine at a glance the type of fault in the armature.

As the armature is rotated, a transient voltage is produced every time the brushes cross from one set of bars to the next, and this interferes with the desired image on the cathode-ray screen. A photoelectric blanking device is employed to eliminate this objectionable factor by removing the image from the screen during the transient periods. A disk, *K*, is locked onto the armature shaft in such a position that a beam of light can pass through a hole in the disk only when a commutator bar is centrally located under a brush. When the edge of the commutator bar approaches the brush, the beam of light is interrupted and the photoelectric device, *L*, acts on the grid of the cathode-ray tube to remove the beam. After the commutator has rotated sufficiently for the brushes to be well established on the next pair of commutator bars, the photoelectric device replaces the image on the cathode-ray screen.

The armature can be rotated quite fast and an individual image flashed on the screen for each coil in the armature. As many as 52 separate coils per second have been tested by this method. However, it is unnecessary to go to this extreme. In practice, about 10 sec are employed to test all of the coils on the armature.

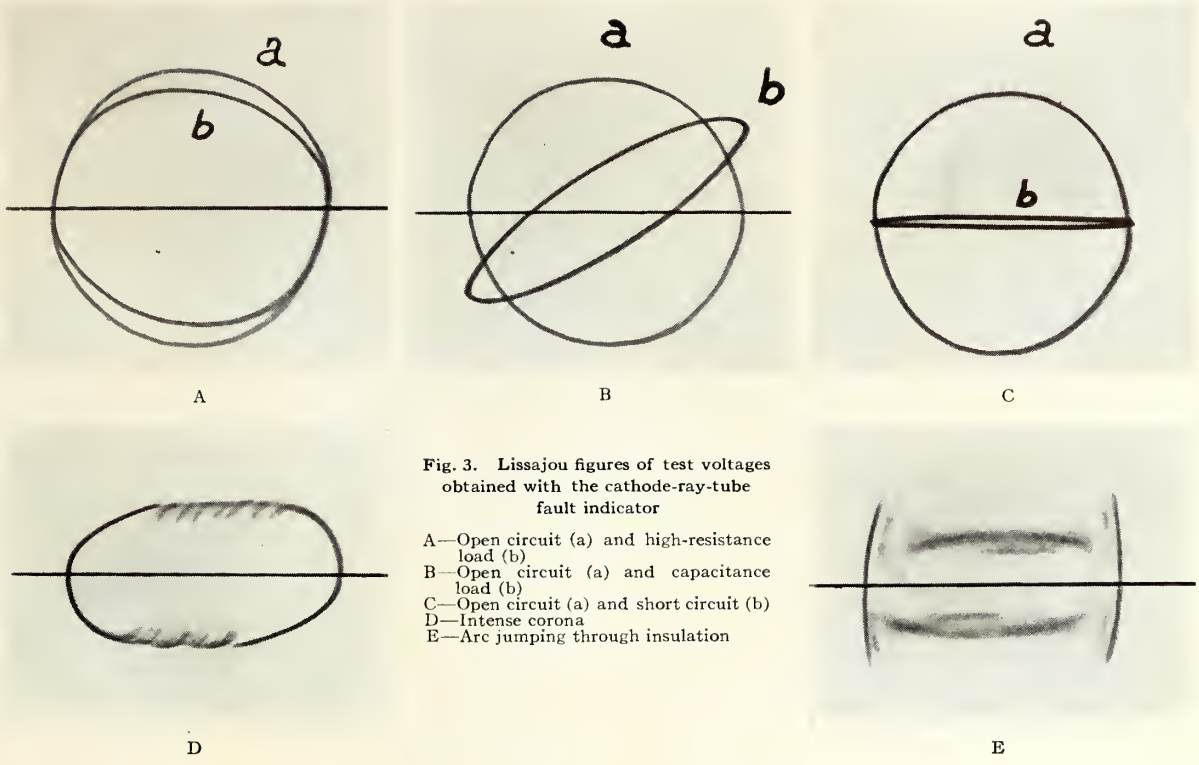

Fig. 3. Lissajou figures of test voltages obtained with the cathode-ray-tube fault indicator

A—Open circuit (a) and high-resistance load (b)
B—Open circuit (a) and capacitance load (b)
C—Open circuit (a) and short circuit (b)
D—Intense corona
E—Arc jumping through insulation

Commutator Analyzer

For many years the manufacturers of commutators have depended on field experience as an indication of quality. Whenever a change in design or manufacturing process was introduced, there was no direct method of comparing the new product with the old. Once again the cathode-ray tube has provided a video test which enables the commutator to be studied under various operating conditions.

The commutator is supported on and driven at high speed through a steel wire. An optical system is so arranged that a light beam passing on a tangent to the commutator is modulated by the commutator bars. The light is directed or reflected thence to a photocell which, in turn, supplies an amplifier and a cathode-ray tube. The sweep frequency of the cathode-ray beam is synchronized with the rotational speed of the commutator so that one revolution of the commutator is made while the beam sweeps once across the screen. A slight modulation in the light beam is translated to a vertical deflection of the cathode-ray beam; hence a high commutator bar appears as a stationary vertical impulse, regardless of the rotational speed of the commutator.

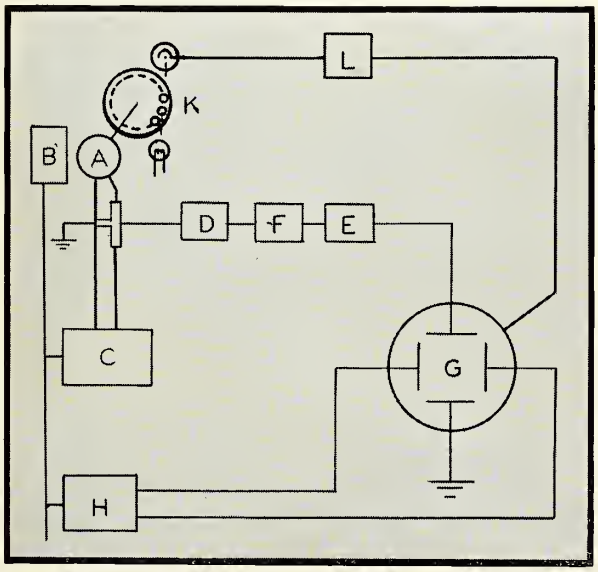

Fig. 4. Block diagram of the high-speed armature-testing machine

An indication of the sensitivity of the equipment is given in the following examples: A lacquer film 0.0001 in. thick was placed on one bar, and the impulse measured on the cathode-ray tube was 2 in. high. On another commutator it was discovered that a small film of oil was thrown out at two points between adjacent commutator bars, when a commutator speed of 16,000 rpm was attained. Observing this phenomenon on the cathode-ray screen showed that two impulses gradually formed and grew to an amplitude of about 1½ in.

The chamber in which this commutator is rotated can be supplied with heat so that the operation of the commutator can be observed under normal or accelerated operating conditions. This device has not been applied as a production test of any extent, but a machine is now being constructed for the purpose of testing commutators for certain important applications by this video test method.

Although extensive application has not been made of video production-test machines, nevertheless it has been successfully applied in several important high-production lines where high-speed testing, compatible with quantity production, must be accomplished with adequate precision.

MEASUREMENTS, AGAIN

By Everett S. Lee, Engineer of the General Engineering Laboratory of the General Electric Company, and Guest Editor of the REVIEW.

MEASUREMENTS abound everywhere. Every act of man is permeated with measurements. They pervade all and every operation and performance, whatever or wherever it may be. In the home, in the shop, or at play, measurements are there. And as man visualizes, he is instinctively measuring, comparing this value with that, sensing through a mental measurement an enlarged opportunity or a new venture. The possibilities of the new are continually being contrasted with the old, a continuous procession of measurements.

The appraisal of any venture is a measurement. The timing of any production is a measurement. The evaluation of any performance is a measurement. First, last, and all the time, measurements persist.

This is so in every field of endeavor, with every person. Nothing better demonstrates this universality of measurements than the newspaper—itself the universal medium through which we acquire our day-to-day knowledge of world events. On the first page is a succession of measurements. The issue number is a measurement; the date is a measurement; the price is a measurement. The front-page news is all measurements: so many miles advanced, so many people injured, so many gallons of oil available, so many days to learn the fate of wrong. Continuing throughout the other pages is a procession of measurements: the prices quoted in the display advertisements, the quality statements about the goods, the addresses of the advertisers, the philosophy of the editorials, the injustices claimed in the Letters from the People, the results on the sporting page, the stock-market reports, the classified advertisements—measurements everywhere.

The familiarity with which measurements are utilized by everyone has resulted in many people taking them more or less for granted, certainly without conscious thought as to how they have been provided with those measurement conveniences. Yet a whole measurements industry has been built in which scientists and engineers apply their fundamental knowledge to providing not only measuring instruments for every conceivale fact-finding purpose but also measuring technique for every knowledge-acquiring exploration. Every field has been invaded, every engineering realm has been included, every performance considered.

Great progress has been made. Nevertheless, the end is not yet, nor is it in sight, nor will it ever be so long as man is as we know him to be. Measuring instruments and measuring technique are as good as the fundamental knowledge of materials and processes which man has come to know and understand at any given time. However, the urge to new achievement spurs his researches and studies. Using the knowledge and measuring ability available to him at the time, he uncovers new knowledge for new advances. Thus measurements and new knowledge progress together, at one time the measurements pointing to the knowledge, at another time the new knowledge being the spur to new measurement achievements.

The power of war stimulates measurements enormously. The concerted endeavor to obtain from every performance the optimum of useful achievement, the impelling urge to obtain new and unheard of and "impossible" performance, the desire to lead—to be better than the other fellow—all join to bring from the scientist and the measurements engineer new and better measuring methods and instruments and devices to the end that the unseen is seen, the unheard is heard, the unknown is known. And the widespread demand for these services attests their vital need.

The famous statement of Lord Kelvin, that "when you can measure what you are speaking about, you know something about it," has rung true through all the years. To the scientists and engineers who have made their life work the giving of measurements to the people is dedicated this publication.

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